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ERRATA.

Vol 26, 1935 Page 539, line 31, for " 170 shillings " read " 3,400 shillings "

Vol 27, 1936 ,, 8, line 14, for " *Notostria* " read " *Notostira* "

,, 83, 20 lines from end, for " *Locutsa* " read " *Locusta* "

,, 228, 19 lines from end, for " $\Sigma(x-\bar{\ })\ (y-\bar{y})$ " read " $\Sigma(x-x)\ (y-y)$ "

,, 228, 15 lines from end, for " parasitism " read " larval survival "

,, 228, 14 lines from end, for " – " read " $\bar{y}$ "

,, 335, 14 lines from end, for " *cresophontes* " read " *cresphontes* "

,, 386, line 20, for " Bainbridge Fletcher " read " Bainbrigge Fletcher "

,, 470, line 2, for " Berkshire " read " Buckinghamshire "

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,, 593, 4 lines from end, for " *inaura* " read " *maura* "

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IMPERIAL INSTITUTE OF ENTOMOLOGY.

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VOL. 27. 1936.

THE GROWTH-CHANGES AND STRUCTURE OF THE EGG OF THE AFRICAN MIGRATORY LOCUST, *LOCUSTA MIGRATORIA MIGRATORIOIDES*, R. & F. (ORTHOPTERA, ACRIDIDAE).

By MITHAN LAL ROONWAL, Ph.D.

(*From the Entomology Department, Zoological Laboratory, Cambridge.*)

Introduction.

The eggs of locusts, like those of some other insects, show the interesting feature of increasing in size during development. Since a large amount of moisture in the soil in which the eggs develop is a necessary prerequisite to successful embryonic growth, it seemed probable that the increase in size of the eggs was largely due to the absorption of water from the soil and in the following account this thesis has been proved.

The structure of the egg-wall of the ACRIDIDAE has been the subject of many investigations since the work of Leuckart (1855), but almost all these accounts are either inaccurate or incomplete. The present description of the structure of the egg-wall of *Locusta migratoria migratorioides* claims to be the first accurate and complete account of the egg-wall of an Acridid. The micropylar apparatus has been recently investigated by Husain & Roonwal (1933) in some of the principal subfamilies of the ACRIDIDAE and the account of *Locusta* given here confirms their observations.

It is with great pleasure that I take this opportunity of expressing my sincere thanks to Professor J. Stanley Gardiner, F.R.S., for accommodating me in the Zoological Laboratory, Cambridge. To Dr. A. D. Imms, F.R.S., I owe a deep debt of gratitude for his kindly guidance and friendly counsel throughout the progress of this work.

Material and Methods.

The eggs used in this work were laid by *Locusta migratoria migratorioides*, which is kept breeding from generation to generation in the Entomological Field Station at Cambridge. The original stock consisted of eggs laid by this locust in the phase *gregaria* near Khartoum. The supply was sent by Mr. A. H. Wood of the Gezira Agricultural Research Service to Dr. A. D. Imms, who received them in June 1933. For the purpose of the present study, only eggs laid by locusts in the phase *gregaria* were utilised.

For sectioning, the eggs were cut transversely into two halves, and the posterior half, containing the micropylar apparatus, was fixed in hot alcoholic Bouin's Fluid and cut by the carbolic acid-water method already described by me (Roonwal, 1935). In a few cases the yolk was carefully scooped out of the egg and the egg-wall cut in wax, without any special treatment. Sections were cut from 5 μ to 12 μ thick. Staining in acid fuchsin and in picro-nigrosin gave good differentiation. The eggs were kept in moist sand and incubated at $33° \pm 0°5$C.

Growth-Changes in the Egg.

Oviposition and General Characters of the Egg.

Oviposition.—The process of oviposition was observed in Fedorov cages and is very similar to that described by Fedorov (1927) in *Anacridium aegyptium*. A detailed description of this process in *Locusta*, therefore, is not given here. Nikolsky (1925) has observed this process in the Migratory Locust in special cages, which, however, he does not describe. He wrongly shows (p. 210, fig. 26) the valves of the ovipositor as being open during this process. Actually they are closed while the egg is passing out. Females lay readily even though deprived of males during oviposition, but, if present, the male usually continues to sit on the back of the female during the whole process of egg-laying. The number of eggs in a pod varied from 22 to 81.

Colour of the egg.—The freshly laid egg is pale yellow in colour, owing to the yolk shining through the whitish, translucent chorion. Within about 30–40 minutes, however, it turns brown, the posterior pole becoming particularly dark. After about three days the posterior end of the egg begins to turn slightly greyish and this change proceeds anteriorly with the growth of the embryo. The yolk, it may be added, becomes more and more restricted to the part of the egg anterior to the embryo. At the time of blastokinesis the entire posterior half of the egg is greyish. This colour is gradually lost as the embryo becomes whitish and opaque with age. Finally, when the egg is about to hatch, it assumes a dirty brown colour and the red embryonic eyes are visible through the egg-wall at the anterior end.

Shape of the egg.—Typically, the freshly laid egg is shaped more or less like a slightly curved cylinder, tapering towards both ends, which are rounded. Variations from the typical form are not infrequent and are shown in fig. 1, **a–d.** The posterior end of the egg is directed caudad in the ovary and the egg-calyx, and downwards in the egg-pod. It is more flattened than the anterior end. The latter extremity is directed cephalad when the egg is in the ovary and the egg-calyx, and upwards when in the soil. Lying in a slight depression, at the posterior end, is a ring of micropylar canals. The convex and concave surfaces of the egg may be named dorsal and ventral respectively since, in the ovary, the former is directed towards the dorsal side of the parent and the latter towards the ventral. The eggs show a definite orientation not only in relation to the body of the parent but also to that of the future embryo. The germ disc is formed at the posterior pole and the head of the early embryo (pre-blastokinesis stage) is directed towards that same extremity. The germ band lies on the concave (ventral) surface of the egg and the ventral side of the early embryo is directed towards that same surface. After blastokinesis, however, the embryonic head points towards the anterior end of the egg and the embryonic ventral side towards the dorsal side of the egg. Thus, the locust egg is a perfect example of Hallez's law (1885–86) of the orientation of insect eggs.

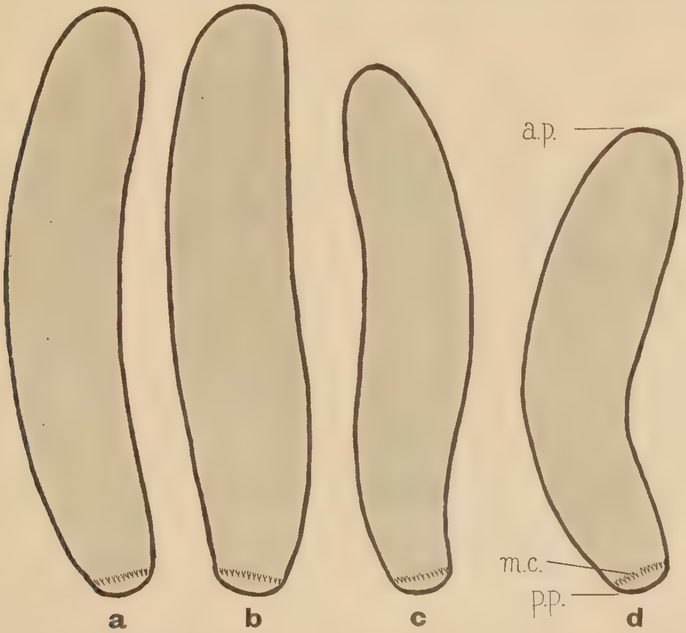

Fig. 1. Freshly laid eggs showing various forms met with (× about 12): **a,** normal form; **b–d,** variants; *a.p.*, anterior pole of egg; *m.c.*, micropylar canals; *p.p.*, posterior pole of egg.

Size of Eggs.

All measurements were made on fresh eggs and under a binocular microscope. The length was measured as a straight line joining the two poles of the egg and the width as the greatest diameter of the egg about mid-way between the two poles. Measurements of the following three stages were made, care being taken to provide comparable samples in each case :—

A. *Freshly laid eggs.*—From the time of oviposition to about 12 hours afterwards.

B. *Half developed eggs.*—From the beginning of blastokinesis until the end of that process. This provides a very convenient stage for two reasons: firstly, that it can be easily recognised and thus comparable samples can be taken; and secondly, because it falls roughly half-way between A and C—actually a day nearer to A than to C.

C. *Fully developed eggs.*—Usually from pods some eggs from which have already hatched.

Tables I and II give the frequency distribution of the samples with regard to length and width in classes of 0·5 mm. magnitude. The apparent departure of the distributions from normality is partly explicable as being due to grouping effect. The means are calculated as for a normal population distribution. It is seen that the egg increases considerably in size during development. The length increases from

5·68±0·33 mm. to 7·85±0·61 mm. or a total mean increase of about 1·38 times. The width increases from 1·18±0·24 mm. to 1·99±0·06 mm. or a total mean increase of about 1·69 times. It is worthy of note that in both length and width, but more particularly in the latter, the increase during the first half or pre-blastokinesis period is markedly greater than during the second half or post-blastokinesis period, i.e., by about 1·6 times in length and about 4 times in width.

TABLE I.

Measurements of Length of Eggs (in mm.).

	Frequency in mm.								Total number of samples	Arithmetic mean	Standard deviation	Standard error of mean
	4·5	5·0	5·5	6·0	6·5	7·0	7·5	8·0				
A. Freshly laid eggs ...	1	—	46	28	1	—	—	—	76	5·68	0·33	0·04
B. Half developed eggs	—	—	—	3	21	46	2	6	78	6·92	0·43	0·05
C. Fully developed eggs	—	—	—	2	2	10	47	7	68	7·85	0·61	0·07

TABLE II.

Measurements of Width of Eggs (in mm.).

	Frequency in mm.			Total number of samples	Arithmetic mean	Standard deviation	Standard error of mean
	1·0	1·5	2·0				
A. Freshly laid eggs ...	49	27	—	76	1·18	0·24	0·03
B. Half developed eggs	—	32	46	78	1·82	0·25	0·03
C. Fully developed eggs	—	1	67	68	1·99	0·06	0·01

The phenomenon of the increase in size of eggs during development is of comparatively rare occurrence among those animals whose eggs are bounded by a firm wall like the chorion of insects. The presence of this phenomenon among the latter is, therefore, of some interest. Probably the earliest reference to it is that by Rathke (1844), who mentions an increase in the size of Phryganiid (Trichoptera) eggs, as well as those of *Gryllotalpa* (Orthoptera), during development. Subsequent authors have recorded it in several other groups of insects as given below :—

Orthoptera.—Gryllidae (Rathke 1844, Patten 1884, Heymons 1895) ; Blattidae (Patten 1884) ; Tettigoniidae (Patten 1884) ; Acrididae (La Baume 1918, Roonwal, present paper).

Dermaptera.—Forficulidae (Heymons 1895).

Rhynchota.—Capsidae (Torre-Bueno 1920, Steer 1929, Austin 1931, 1932, Johnson 1934).

Hymenoptera.—Tenthredinidae (Enslin 1914, Peacock 1928, Kerenski 1930) ; Braconidae (Jackson 1928) ; other parasitic Hymenoptera (*vide* Imms 1934, p. 161) ; Formicidae (Donisthorpe 1927).

Coleoptera.—Lamellicornia (Smith & Hadley 1926, Kerenski 1930 ; also *vide* Imms 1934, p. 532).

Diptera.—Agromyzidae (Thorpe 1930).

The precise cause of this swelling is, in most of these cases, unknown. For the sawflies, some authors maintain that the egg, which is generally laid in a plant stem, absorbs water from the plant juices. Peacock's (1928) experiments on rearing sawfly eggs *in vitro* support this. Others are of the opinion that the increase is due to the intake by diffusion of food-material by the embryo (*vide* Bischoff 1927).

TABLE III.

Degree of Increase in Dimensions of Eggs.

Between stages	Times increase	
	In length	In width
A and B	1·22	1·54
B and C	1·13	1·09
A and C (total increase) ...	1·38	1·69

It is certain that the cause of this increase in size of eggs of *Locusta* and other ACRIDIDAE during development is the absorption of water from the surrounding medium, *i.e.*, from moist soil. As shown in the next section, the water-content of the egg increases during development from about 53 per cent. of the total wet weight of the egg at the time of laying to about 83 per cent. just before the emergence of the nymph. It is well known that locust eggs either shrivel up or die in dry soil or, in a suitable degree of dryness, their development may be suspended for a very long time—several months—and made to restart on the addition of an adequate amount of moisture to the soil. It is interesting to note that the eggs of several of those insects in which this phenomenon of the increase in size has been recorded develop, as a rule, in very high humidities, approaching the saturation point. The increase in size in these cases also is very probably due to the same cause as in the locust egg. This was experimentally shown by Kerenski (1930) for the beetle *Anisoplia austriaca*. Johnson (1934) also records an increase in the water-content of the egg of the Capsid, *Notostria erratica*, during development. It may confidently be predicted that the phenomenon of the increase in size of eggs during development will be found of a more general occurrence among insects than has hitherto been recorded, more especially in those cases where the eggs develop, as a rule, in humid surroundings.

Weight and Moisture Content of Eggs.

Eggs were washed with distilled water, using a fine brush to remove sand particles and other foreign material adhering to them. After this they were quickly dried on a filter paper and weighed. Drying was done in an oven at 100°C. The eggs were then cooled over H^2SO^4 and weighed. It was found more convenient to weigh the eggs in batches rather than singly. Weighings of stages A, B and C (*vide* pp. 6 and 7) were taken.

Tables IV–VI give the mean figures calculated for wet and dry weights, loss in weight due to drying and the percentage of moisture. The wet weight of a single egg increases during development by about 2·2 times. The increase during stage A–B is nearly 15 times that during stage B–C. The absolute amount of water increases during development by about 3·3 times. Of this, the increase during stage A–B is nearly 16 times that during stage B–C. The percentage of moisture in a single egg (*i.e.*, the amount of moisture in relation to wet weight) increases from $51{\cdot}92 \pm 3{\cdot}53$ in the freshly laid egg to $77{\cdot}79 \pm 1{\cdot}49$ in the half-developed (stage B) and $82{\cdot}36 \pm 2{\cdot}14$

in the fully developed egg. The total increase is thus 30·44 per cent. The greater part (25·87 per cent.) of this increase occurs during stage A–B, the increase during B–C being only 4·57 per cent.

TABLE IV.

*Mean Weight (in grams) of a single freshly laid Egg (Stage A).**

Particulars of weight	Arithmetic mean	Standard deviation	Standard error of mean
Wet weight	0·0063	0·0008	0·00008
Dry weight	0·003	0·0004	0·00004
Moisture content ...	0·0033	0·0002	0·00002
Percentage of moisture in terms of wet weight ...	51·92	3·53	0·33

* The total number of eggs weighed = 113. They were weighed in 12 batches of 8–10 eggs in each.

TABLE V.

*Mean Weight (in grams) of a single half developed Egg (Stage B).**

Particulars of weight	Arithmetic mean	Standard deviation	Standard error of mean
Wet weight	0·0135	0·0012	0·0001
Dry weight	0·003	0·0003	0·00003
Moisture content ...	0·0105	0·001	0·0001
Percentage of moisture in terms of wet weight ...	77·79	1·49	0·15

* The total number of eggs weighed = 104. They were weighed in 13 batches of 5–10 eggs in each.

TABLE VI.

*Mean Weight (in grams) of a single fully developed Egg (Stage C).**

Particulars of weight	Arithmetic mean	Standard deviation	Standard error of mean
Wet weight	0·014	0·002	0·0001
Dry weight	0·0024	0·0002	0·00002
Moisture content ...	0·011	0·001	0·0001
Percentage of moisture in terms of wet weight ...	82·36	2·14	0·18

* The total number of eggs weighed is as follows :—For wet weight, 181 eggs in 23 batches of 2–18 eggs in each ; for the rest, 150 eggs in 17 batches of 2–18 eggs in each.

The dry weight of a single egg falls from ·003±·0003 gms. to ·0024±·0002 gms. during development, a total decrease of about 20 per cent. It will be seen from Tables IV–VI that the dry weight remains constant during stage A–B. But, in my opinion, this is misleading. The size of eggs, and consequently their dry weights, vary very much from one egg-pod to another but are reasonably uniform within the same pod. Therefore, in the case of a minute quantity like the dry weights, values obtained for the various stages from eggs belonging to the same egg-pod are much more suitable for comparison than those obtained from different pods. Table VII shows the dry weights of eggs belonging, in each series, to a single egg-pod.

TABLE VII.

Dry Weights of Eggs belonging to the same Egg-pod in each Series.

Serial number	Calculated dry weight of a single egg					
	A. Freshly laid		B. Half developed		C. Fully developed	
	Number of eggs in each experiment	Dry weight of one egg	Number of eggs in each experiment	Dry weight of one egg	Number of eggs in each experiment	Dry weight of one egg
1	8	·00306	10	·00291	7	·00261
2	8	·00319	7	·00269	3	·00257
3	10	·00334	9	·00318	18	·00253
	8	·00338				
4	10	·00367	5	·00356	...	...
5	10	·0027	7	·00259	...	...
6	10	·00291	6	·00312*	...	...
			5	·00286		
7	9	·00339	10	·00312	...	...
			7	·00301		
8	...	...	10	·00313	12	·00261
9	...	...	7	·00267	2	·00225
10	...	...	9	·00296	2	·00255
11	...	...	10	·00268	10	·00248
					6	·00242

It clearly indicates that a fall in dry weight occurs not only during stage B–C but also during stage A–B.* The greater part of the total decrease occurs during stage B-C. Farkas (1903) has recorded a 10 per cent. loss in dry weight of the silkworm egg during embryonic development. A similar fall in the dry weight of the egg-material has been observed in other animals as well as, for instance, in the trout, *Salmo fario* (Gray 1926). In such cases it is to be explained as due to the energy expended upon the normal activities of the developing embryo.

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* In only one case, marked with an asterisk, is there an increase in dry weight from stage A–B. A second batch of eggs from the same pod, however, shows the usual decrease in dry weight.

The foregoing observations indicate that for successful and continuous development the presence of water is necessary. The withholding of water is one of the factors which leads to a suspension of development in locust eggs, such as happens under arid conditions in a state of nature. Uvarov (1928) suggests that this may indeed be an important cause for the origin of embryonic diapause. Many of these so-called diapauses can be traced to the direct effect of external conditions and can be broken by suitably altering them. To such cases it would be best to apply the simple term " suspension of development." The use of the term " diapause " would then be restricted only to those cases where this suspension is not directly traceable to the external environment but is the outcome of an inherent rhythm which is unaffected by the changing of external conditions. Water absorption by eggs was also shown by Dampf (1925) for *Schistocerca paranensis*, by Bodine (1925) for *Melanoplus differentialis*, by Kerenski (1930) for the beetle, *Anisoplia austriaca*, and by Johnson (1934) for the Capsid, *Notostira erratica*. Besides insects, other animal eggs also, as for instance those of trout and some lizards (Gray 1926) and the Crustacean *Hemimysis* (Manton 1928), absorb water during development from the external environment. In locust eggs, both the increase in the amount of water and in the dimensions of the egg are greater during the first half period of development (stage A–B) than during the second half period (stage B–C). It may be pointed out that in some insects loss in weight, due to decrease of the water-content, has been observed. Tichomiroff (1885) found this in the eggs of *Bombyx mori*. In this insect, the greatest change was observed to occur during the early period of development and its decrease coincided with the dorsal closure of the embryo which, according to Tichomiroff, hindered further loss of water. Slifer (1930) inclines to apply the same explanation to the eggs of the grasshopper, *Melanoplus differentialis*, only " the wall of the embryo now preventing the passage of the water into, rather than out of, the egg." She has further shown (1934), from a study of the behaviour of *Melanoplus* embryos in anisotonic balanced salt solutions, that the embryos are able to withstand considerable fluctuations in the osmotic pressure of the environment. This ability enables the eggs to tide over adverse environmental conditions regarding moisture, provided that these conditions are not too prolonged.

and

The Structure of the Egg.

The Egg-wall.

It is a curious fact that no accurate and complete account of the structure of the egg-wall of an Acridid exists. Descriptions available in literature are many and varied but are almost all incomplete or inaccurate. Leuckart (1855) studied the structure of the egg-wall and the micropyle of *Oedipoda coerulescens* and *Stenobothrus lineatus*, *Myrmeleotettix biguttatus* and *Chorthippus variabilis*. This author studied only whole mounts and did not arrive at an understanding of the true nature of the chorionic sculpturing. He says, " Das Chorion . . . zeigt zahllose Poren, die dicht neben einander stehen und weit in die Tiefe hineindringen " ; he makes no mention of the vitelline membrane. Korschelt (1887) gave an account of the formation of the egg-wall in *Chorthippus dorsatus*. According to him, during the process of chorion secretion, ridges (tubercles) are formed which, however, disappear after a time. Whether the exo- and endochorion can still be distinguished in the mature egg is not mentioned. He describes a thick vitelline membrane which, according to him, is formed after the chorion. In the young egg he describes a large pore at one of the poles (? anterior) involving both the vitelline membrane and the chorion and through which the young egg is nourished. Packard's (1878) account of the egg-wall of the Rocky Mountain Locust (*Melanoplus spretus*) is very inaccurate. He regarded the actual chorion as " . . . a mere covering of excreted matter similar in nature to the mucous or sebific fluid . . . " ; the vitelline membrane he refers to as the chorion.

Graber (1888) in *Chorthippus variabilis*, Fieb., distinguishes between exo- and endochorion, but says that there is " . . . in Gegensatz zu den meisten anderen Insekten, keine Dotterhaut . . ." ; furthermore, he terms the micropylar pole the anterior pole. Plotnikov (1926, pp. 271–272) gives a fairly accurate account of the chorionic sculpturing of *Locusta migratoria migratoria* as seen in surface view, but the sectional view figured by him is too small to show details. He does not distinguish between exo- and endochorion, nor does he mention the vitelline membrane. McNabb's (1928) description of the structure of the egg-wall in the Acridid *Circotettix verruculatus* is entirely inaccurate. She says, " The egg is surrounded by two membranes : the chorion, a tough chitinous covering and an inner protoplasmic membrane. The fine fibrillar and granular structure of the chorion of the laid egg may be seen in Fig. 28." What she terms the chorion and figures as such is in reality the vitelline membrane. Campbell (1929), in testing for chitin in the eggs of *Melanoplus differentialis*, makes the very ambiguous statement that " The chorion does not contain chitin but when the egg has developed to a point where the blastoderm cells have laid down a membrane upon the chorion, that membrane contains chitin." In no insect is such a membrane laid down by the blastoderm cells. Nelsen (1931) correctly figures the egg-wall of *Melanoplus differentialis*, but in a later paper (1934 (a), Plate IV, fig. 16) on the same insect he wrongly labels the vitelline membrane as the chorion and does not figure the latter at all.

The egg-wall of *Locusta* consists of two distinct constituents—the chorion and, inside it, the vitelline membrane.

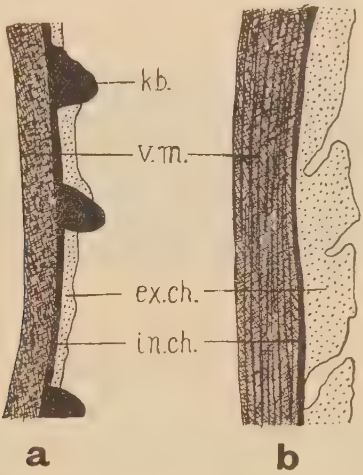


Fig. 2. **a,** longitudinal section of the egg-wall of a freshly laid egg (note the felt-like structure of the vitelline membrane) (x 780) ; **b,** longitudinal section of the egg-wall of an egg about to hatch (note the swollen and laminated structure of the vitelline membrane) (x 780) ; *ex.ch.*, exochorion ; *in.ch.*, endochorion ; *kb.*, protuberances of the endochorion ; *v.m.*, vitelline membrane.

The chorion.—It consists (fig. 2) of two distinct layers, the exochorion and the endochorion. The endochorion is studded with tubercles of various sizes, ranging from minute dots to nearly 10 μ in surface view, and about the same in vertical section. These tubercles are the cause of the dotted sculpturing of the chorion when seen in a surface view (fig. 3 *a*). They are not arranged in a definite polygonal pattern, as is the case in several other Acrididae, but lie irregularly. They are absent in the micropylar area (see below) and are very close together at the two poles, especially the posterior. Husain & Roonwal (1933) have shown that the chorionic sculpturing among the ACRIDIDAE is generally characteristic of each form ; an extensive comparative study of this subject should give interesting results.

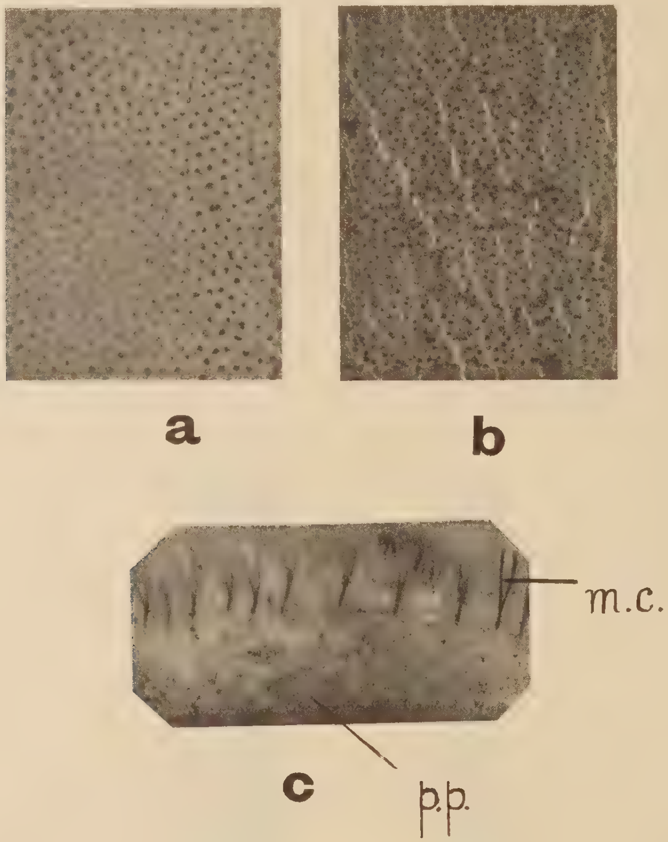


Fig. 3. **a,** photo-micrograph of a portion of the egg-wall of a freshly laid egg, showing chorionic sculpturing, the black dots representing the minute protuberances of the endochorion (x 76) ; **b,** ditto, from an egg about to hatch, showing fissures caused by the cracking of the chorion (x 76) ; **c,** photo-micrograph of a portion of the egg-wall near the posterior pole of a freshly laid egg, showing some of the micropylar canals. Note the absence of the chorionic sculpturing in the region of the canals. The micropylar canal on the extreme right has been outlined in ink (x about 156) ; *m.c*, micropylar canal ; *p.p.*, posterior pole of the egg.

The exo- and endochorion differ in structure and properties. The latter stains an intense red with acid fuchsin and has a homogeneous, highly refractile and compact-looking structure. It has a more or less uniform thickness of about 1 μ all round the egg and is closely attached to the vitelline membrane. The exochorion forms a closely investing layer over the endochorion and its tubercles without the formation of any trabeculae or air spaces in between (*cf. Schistocerca gregaria, Blattella germanica*, etc.). It is less compact-looking than the endochorion, measures about 2–3 μ in thickness and stains only faintly with acid fuchsin. In some examples the exochorion is very feebly developed, in others it may be absent.

At the time of laying, the chorion is whitish and nearly translucent. Within about 30 to 40 minutes, however, it turns brown. As the egg increases in size, the chorion, being unable to stretch, splits at several places (figs. 2, *b*, 3, *b*) and finally peels off in irregular patches.

The vitelline membrane.—In some Orthoptera (*Blattella germanica*—Blochmann 1887, Wheeler 1889; *Xiphidium*—Wheeler 1893; *Carausius*—Leuzinger 1925) no definite vitelline membrane has been found. In *Locusta* and other Acrididae, on the other hand, a thick vitelline membrane is present, lying inside and closely adpressed against the endochorion (fig. 2, *a*). It is not a structureless membrane, as has been maintained by all writers on insects, but exhibits, in a freshly laid egg, a distinct felt-like structure. This is so in all the Acrididae I have examined.

With the growth of the egg, the vitelline membrane undergoes an increase in thickness and acquires a definitely laminated structure superimposed upon the original felt-like condition. These changes first become evident in eggs about 75 hours old. Table VIII indicates the changes in the vitelline membrane at various stages of development of the egg.

TABLE VIII.

Showing Changes in the Vitelline Membrane.

Stage	Thickness of vitelline membrane		Structure of vitelline membrane
	At the poles	Elsewhere	
Freshly laid	12 μ	5μ	Felt-like structure
About 75 hours old ...	18 μ	10μ	Beginning of laminated structure
During blastokinesis ...	20 μ	11μ	Clearly laminated
About to hatch	20 μ	11μ	Ditto

It will be evident from the foregoing table that the vitelline membrane becomes more than doubled in thickness at the time of blastokinesis. The cause of these curious changes in the vitelline membrane is probably related to the appearance of a fluid which first starts accumulating in the posterior part of the egg at about the 75 hours stage. At the time of blastokinesis this fluid fills almost the entire posterior half of the egg and also extends between the serosa and the vitelline membrane. It is most likely that the absorption of this fluid by the vitelline membrane not only causes it to swell but is also responsible for the change into a laminated structure.

The Micropylar Apparatus.

The structure of the micropylar apparatus in *Schistocerca gregaria* and a number of other Acrididae has been studied recently (Husain & Roonwal 1933) and reference should be made to that paper for a historical account. Here I shall reaffirm our conclusion of the uniformity of the micropylar structure in the family Acrididae. I might, however, mention that the account of McNabb (1928, p. 56, Plate I, fig. 4) of the micropylar canals of the Acridid *Chrotophaga viridifasciata* is apparently inaccurate. She describes and figures them as " cylindrical canals " whereas they are funnel-shaped in all the Acrididae. It is evident from her figure that she contented herself with the study of a longitudinal section which grazed the egg-periphery so as to cut several canals obliquely across their wide anterior halves. To gain an insight into the true structure of these canals, accurate longitudinal-vertical as well as transverse sections of the egg have to be examined.

The micropylar apparatus of *Locusta* consists of a ring of long, funnel-shaped, cuticular canals extending around the egg at a distance of about 0·4 to 0·5 mm.

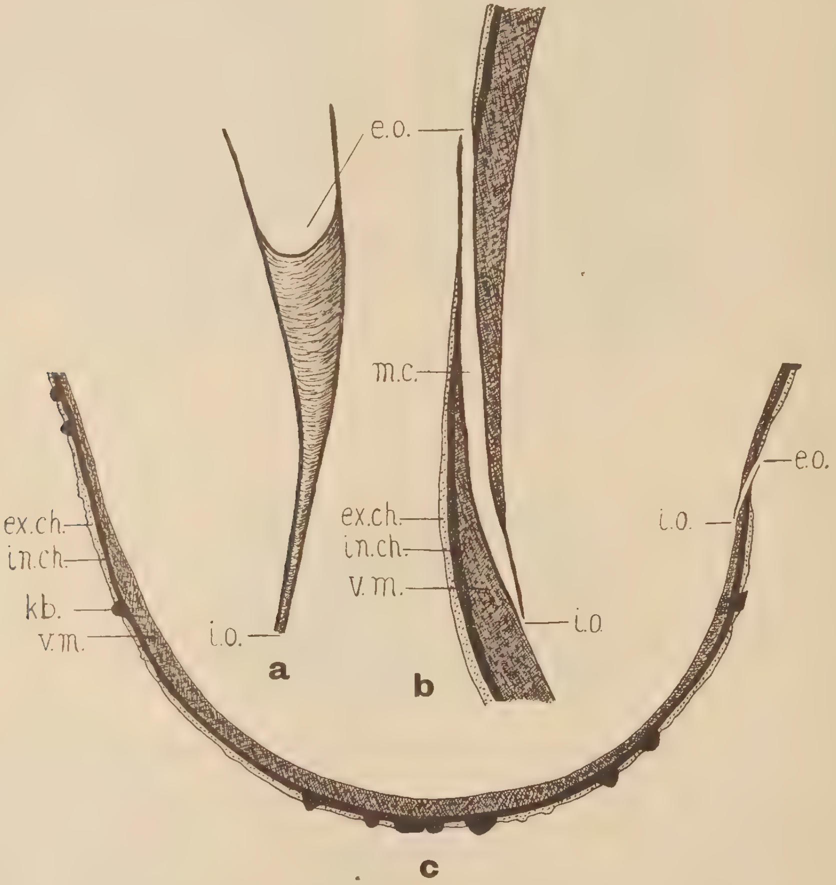


Fig. 4. **a,** outline of a micropylar canal from a freshly laid egg (x 627) ; **b,** longitudinal section of the egg-wall of a freshly laid egg, showing the course of a micropylar canal (x 780) ; **c,** longitudinal section of the posterior end of a freshly laid egg passing right through a micropylar canal and on the left through an inter-canular area (x about 223) ; *eo.*, external opening of micropylar canal ; *ex.ch.*, exochorion ; *in.ch.*, endochorion ; *io.*, inner opening of micropylar canal ; *kb.*, protuberances of endochorion ; *m.c.*, micropylar canal ; *v.m.*, vitelline membrane.

from the posterior pole (figs. 3, **c**, 4 and 5). Their number may vary from 35 to 43. From its shallow and very oblique outer opening or mouth, which is about 8·5 to 28 μ in width, each canal runs obliquely downwards and inwards along the longitudinal axis of the egg. It traverses the entire length of the egg-wall and finally opens into the interior of the egg by means of an extremely fine aperture in the vitelline membrane. The canal narrows as it proceeds inwards. In length the canals may vary from about 60 μ to 116 μ. They generally touch one another at their wider ends, but at the narrower ends they may be separated by as much as 133 μ. Near their mouths the canals are flattened and slightly bent. Further inwards they gradually become oval in cross-section.

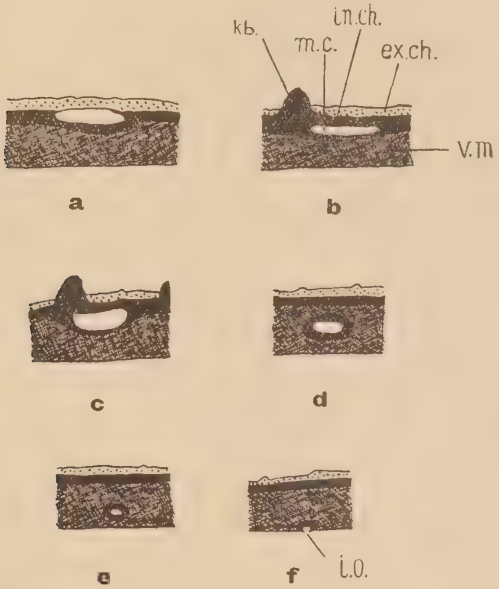


Fig. 5. **a-f,** transverse sections of the egg-wall of a freshly laid egg passing through the various regions of a micropylar canal, starting from the outer opening and going inwards ; **a,** section close to the outer opening of the canal ; **f,** section across the inner opening of the canal (x 780) ; *ex.ch.*, exochorion ; *in.ch.*, endochorion ; *i.o.*, inner opening of micropylar canal ; *kb.*, protuberances of endochorion ; *m.c.*, micropylar canal ; *v.m.*, vitelline membrane.

Summary.

The eggs of *Locusta migratoria migratorioides*, R. & F., increase in size during development. The increase is due to the absorption of water from the surrounding moist soil.

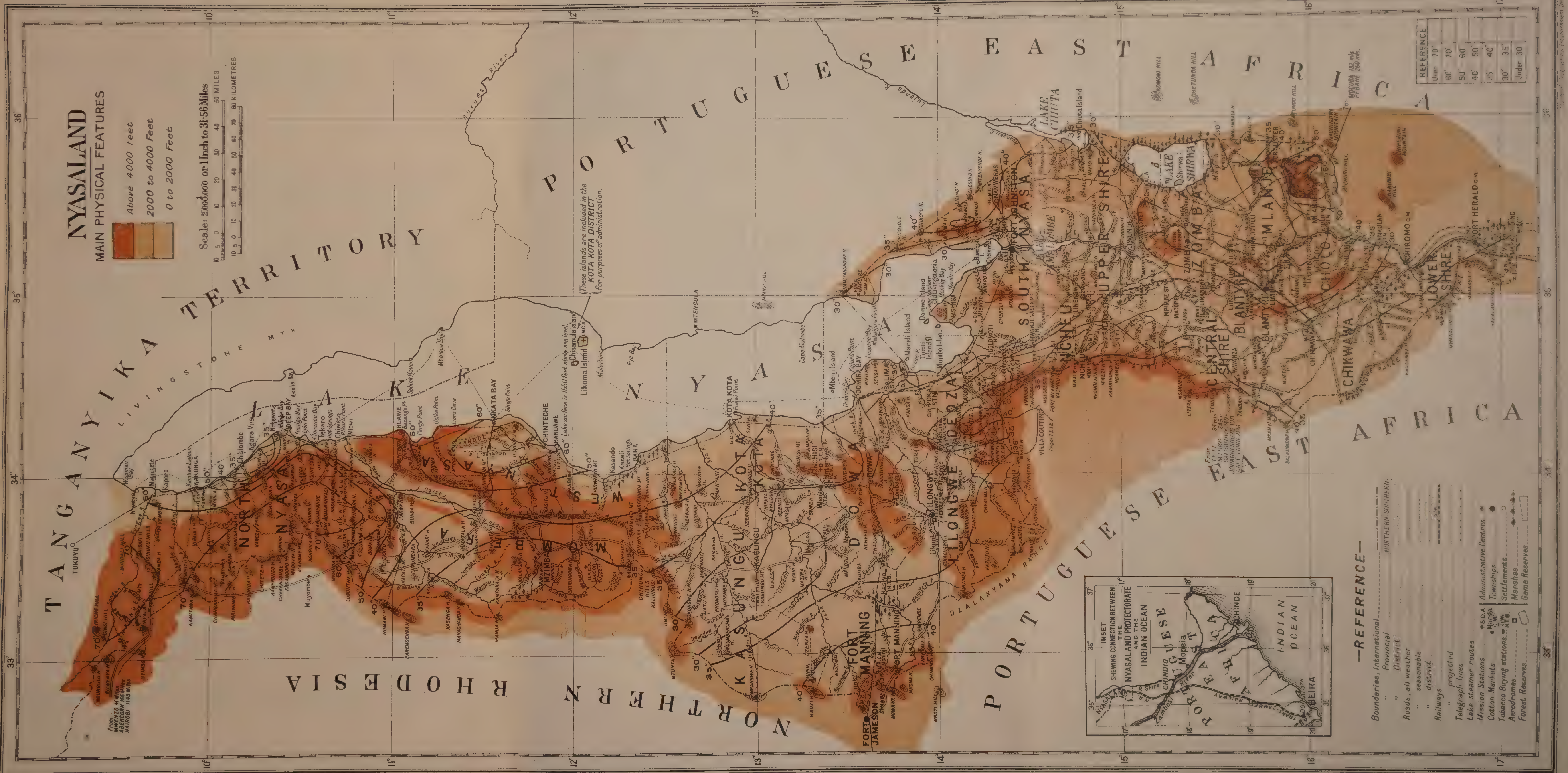
The wet weight of a freshly laid egg is 0·0063±0·0008 gms. and of a fully developed egg 0·014±0·002 gms. The dry weight of a freshly laid egg is 0·003±0·0004 gms. and of a fully developed egg 0·0024±0·0002 gms. The water-content of an egg increases from 51·92±3·53 per cent. of the wet weight in the freshly laid egg to 82·36±2·14 per cent. in the fully developed egg.

The egg-wall consists of an exo- and endochorion and a thick vitelline membrane. The latter has a felt-like structure in the freshly laid egg, but as the egg develops, this membrane increases in thickness and acquires a laminated character.

The micropylar apparatus consists of a ring of about 35–43 oblique, funnel-shaped canals arranged round the egg near its posterior end.

References.

AUSTIN, M. D. (1931). Ent. Mon. Mag. **67.**
——. (1932). J. R. Hort. Soc. **57.**
BISCHOFF, H. (1927). Biologie der Hymenopteren. Berlin.
BLOCHMANN, F. (1887). Morph. Jahrb. **15.**
BODINE, J. H. (1925). J. Exp. Zool. **42.**
BUXTON, P. A. (1932). Biol. Reviews **7.**
CAMPBELL, F. L. (1929). Ann. Ent. Soc. Amer. **22.**
DAMPF, A. (1925). Monogr. Inst. Hig. Num. 3, Mexico.
DONISTHORPE, H. J. K. (1927). British ants. London.
ENSLIN, E. (1914). Die Blatt- und Holzwespen (Tenthredinoidea). In Chr. Schröder "Die Insekten Mitteleuropas," Bd. **3.**
FARKAS, K. (1903). Pflügers Arch. **98.**
FEDOROV, S. M. (1927). Trans. Ent. Soc. Lond. **75.**
GRABER, V. (1888). Denkschr. Akad. Wiss. Wien **55.**
GRAY, J. (1926). J. Exp. Biol. **4.**
HALLEZ, P. (1885). C. R. Acad. Sci. **101.**
——. (1886). *Ibid.* **103.**
HEYMONS, R. (1895). Die Embryonalentwicklung von Dermapteren und Orthopteren. Jena.
HUSAIN, M. A. & ROONWAL, M. L. (1933). Ind. J. Agric. Sci. **3.**
IMMS, A. D. (1934). A general text-book of entomology. 3rd edn. London.
JACKSON, D. J. (1928). Proc. Zool. Soc. Lond.
JOHNSON, C. G. (1934). Trans. Soc. Brit. Ent. **1.**
KERENSKI, J. (1930). Z. angew. Ent. **16.**
KORSCHELT, E. (1887). Nova Acta Acad. Leop. Carol. **2.**
LA BAUME, W. (1918). Monogr. angew. Ent., Nr. 3.
LEUCKART, R. (1855). Arch. f. Anat. u. Physiol.
LEUZINGER, H. (1925). Zur Kenntniss der Anatomie und Entwicklungsgeschichte von *Carausius morosus* Br. I. Jena.
MANTON, S. M. (1928). Phil. Trans. Roy. Soc. Lond., B. **216.**
MCNABB, J. W. (1928). J. Morph. **45.**
NELSEN, O. E. (1931). J. Morph. **51.**
NIKOLSKY, V. V. (1925). The Asiatic Locust. (In Russian.) Leningrad.
PACKARD, A. S. (1878). 1st Ann. Rep. U.S. Ent. Comm.
PATTEN, W. (1884). Quart. J. Micr. Sci. **24.**
PEACOCK, A. D. (1928). Proc. Roy. Phys. Soc. Edinb. **21.**
PLOTNIKOV, V. J. (1926). Insects injurious to cultivated plants in Central Asia. (In Russian.) Tashkent.
RATHKE, M. (1844). Arch. f. Anat. u. Physiol.
ROONWAL, M. L. (1935). Zool. Anz. **110.**
SLIFER, E. H. (1930). Physiol. Zool. **3.**
——. (1934). J. Exp. Zool. **67.**
SMITH, L. B. & HADLEY, C. H. (1926). Circ. U.S. Dept. Agric., No. 363.
STEER, W. (1929). Ent. Mon. Mag. **65.**
THORPE, W. H. (1930). Proc. Zool. Soc. Lond.
TICHOMIROFF, A. (1885). Z. physiol. Chemie **9.**
TORRE-BUENO, J. R. de la. (1920). Bull. Brooklyn Ent. Soc. **15.**
UVAROV, B. P. (1928). Locusts and Grasshoppers. London.
WHEELER, W. M. (1889). J. Morph. **3.**
——. (1893). *Ibid.* **8.**


NYASALAND
MAIN PHYSICAL FEATURES
Above 4000 Feet
2000 to 4000 Feet
0 to 2000 Feet
Scale: 1/2,000,000 or 1 Inch to 31·56 Miles
MILES
KILOMETRES
TANGANYIKA TERRITORY
PORTUGUESE EAST AFRICA
NORTHERN RHODESIA
LAKE NYASA
LIVINGSTONE MTS
NORTH NYASA
WEST NYASA
MOMBERA
KASUNGU
KOTA KOTA
DOWA
LILONGWE
DEDZA
NCHEU
SOUTH NYASA
UPPER SHIRE
CENTRAL SHIRE
BLANTYRE
ZOMBA
MLANJE
CHOLO
CHIKWAWA
LOWER SHIRE
LAKE CHIUTA
LAKE SHIRWA
FORT JAMESON
FORT MANNING
FORT JOHNSTON
KARONGA
LIKOMA ISLAND
These islands are included in the KOTA KOTA DISTRICT for purposes of administration.
Lake surface is 1550 feet above sea level.
DZALANYAMA RANGE
INSET SHEWING CONNECTION BETWEEN THE NYASALAND PROTECTORATE AND THE INDIAN OCEAN
INDIAN OCEAN
CHINDE
BEIRA
—REFERENCE—
Boundaries, International
" Provincial
" District
Roads, all weather
" seasonable
" district
Railways
" projected
Telegraph lines
Lake steamer routes
Mission Stations
Cotton Markets
Tobacco Buying stations
Aerodromes
Forest Reserves
Administrative Centres
Townships
Settlements
Marshes
Game Reserves
REFERENCE
Over 70"
60" 70"
50" 60"
40" 50"
35" 40"
30" 35"
Under 30"

NOTES ON THE RED LOCUST (*NOMADACRIS SEPTEMFASCIATA*, SERV.) IN NYASALAND 1933–34.

By C. Smee.

(Map.)

In common with the rest of southern-central Africa (Uvarov, 1933) the Nyasaland Protectorate was affected late in 1932 by the spread of the sixth generation of the red-winged locust. The course of the invasion, development of subsequent generations, and the damage done have been fully described in the Annual Reports of the Department of Agriculture for the years 1933 to 1934 (Smee, 1934, 1935).

During the work of attempting to limit the damage likely to be done by this locust, observations were made on its habits in the field through two complete years and three breeding seasons. These observations, some of them probably now well-known to those who have been studying this insect, are produced here. It is possible, also, by this time to offer some notes on the seasonal movements of swarms and the factors influencing such movement, at any rate so far as local conditions are concerned. In this work the author wishes to acknowledge the invaluable assistance and advice received from Dr. B. P. Uvarov of the Imperial Institute of Entomology. Acknowledgment of assistance received in the Protectorate has been made in the Departmental Annual Reports.

Oviposition.

Although there seemed to be little selection as regards type of country or soil by the egg-laying females, bare patches of ground between tufts of grass, sites where tree-stumps had been burnt and the earth was almost ashlike, the loose earth of the hillocks made in native gardens and similar situations, were definitely singled out when a swarm settled to lay. As a consequence the concentration of the egg-packets in these places may be enormous. In one such area where natives had planted maize irregularly in bare patches of ground in the jungle, 40–50 egg-packets to the square foot were found concentrated on the spots where the maize had been sown ; the surface of the earth at each spot had the appearance of having been stirred up with a pointed stick and the froth plugs were broken off and lying on the ground, the egg-packets crossing one another in general confusion.

On several occasions numbers of holes were found without eggs having been laid, and sometimes dead adults were present at these places. Laying in the cracks of a disintegrated rock or shale bank was also recorded, but in only one case was a definite observation made that eggs laid in dry, grey sandy soil and subjected to 10 days intense sun failed to hatch, from their appearance being " baked " by the heat.

Accurate records were not obtainable in the field as to how many egg-packets are laid by one female, but a swarm seems frequently to lay in several places over a period of several days. A period of 14 days continuous laying in one place was definitely observed in the Lilongwe district. The adults die off rapidly after (presumably) the last egg-laying, and the fact that in some egg areas a few dead adults are to be found and in others very large numbers suggests that egg-laying takes place more than once.

In the 1934–35 season reports, both European and native, from the Upper Shire district indicated that egg-packets laid in low-lying areas in early November had been destroyed by rain by the end of December, but this failure to hatch may have been caused by parasites, which appeared to be more numerous than in previous years.

Incubation Period.

The only information available on this subject was to the effect that the egg incubation period was approximately 30 days and was not considered to be so dependent on climatic conditions as in the case of other species of locusts. In the field it was not easy to obtain any large number of absolutely reliable dates of egg-laying and the corresponding hatching, owing partly to the fact that egg-laying in one area may continue over a considerable period. Early in 1933, however, records of sufficient authenticity to be of value gave a range of 25 to 32 days, and the vast majority of hatchings appeared to take place in approximately 30 days. In the 1933–34 period it was still more difficult to obtain precise records on account of the extended time during which oviposition occurred, and although some of the earlier layings in the southern part of the Protectorate conformed to the 30-day period, the later ones, particularly in the north, must have taken a longer time to hatch, evidence of some 46 days being produced in one case and over 40 in another. In these areas a continuous, though not exceptionally heavy, rainfall was experienced during practically the whole of January and February 1934, during which this apparently prolonged incubation period took place.

Eclosion and Intermediate Moult.

Eclosion is fairly rapid once the head is free of the shell, 18 minutes being recorded in one case and 20 minutes in another. Hatching in the field was noted to continue from early morning until 12 noon at any rate ; none was actually observed in the late afternoon but it may perhaps occur. The shedding of the membrane enclosing the vermiform larva is usually simultaneous with emergence from the ground, that is to say that most hoppers on emergence have the membrane attached only to the apex of the abdomen and it is at once scraped off on the soil, movement of the abdomen so that the membrane just touches the soil apparently being sufficient. Others, on emergence, have completely discarded their membranes which can be found in the mass of egg-shells. Where vermiform larvae issued with the membrane still enclosing them, both in captivity and in the field, it was noticed that the membrane was wriggled off, not pushed off with the legs or feet.

Normally emergence seems to take place through the froth plug, which thus becomes hollowed out like a tube, only a very flimsy structure remaining. On a few occasions a loose mass of apparently fully-developed embryos was unearthed from some 3 to 4 inches below ground-level. They were certainly without egg-shells, possibly without membranes (though this was not clearly demonstrable) and appeared to be unhealthy. No reason could be found for this occurrence, nor was it ascertained if such hoppers emerged from the ground and survived.

Many empty egg-packets are destroyed rapidly by ants and termites, and ants were observed removing the discarded membranes.

Hopper Bands.

Immediately after removal of the membrane the hoppers move actively in all directions. In an area that has been closely laid over, this brings a number of the newly-hatched ones into contact with vermiform larvae and hoppers emerging from other egg-packets which they promptly attack and devour. It was only at this stage that hoppers were ever seen to destroy other living hoppers, but it was observed in all cases where concentrated egg-laying had taken place.

Where emergence takes place on bare ground, such as a cultivated field, the first movements of the hoppers are continued until shelter is found among some kind of vegetation. This phytophilous habit is very marked throughout the entire existence of a *Nomadacris* hopper band, and very rarely was a prolonged movement over bare ground observed.

The young hoppers congregate in small clumps on weed leaves, fallen trees and grass-stalks, and their movement for several days is very slight. The actual hop of an individual gives the impression of being stronger and higher than with *Locusta* hoppers of a similar age, but their normal reaction to disturbance is to secrete themselves among the grass roots, though whether this is a definitely controlled action or whether it results naturally from the condition of the vegetation in which they normally collect, it would in many cases be difficult to decide. But as even in short grass they will crawl and scramble through the roots to a considerable extent, and show a predilection for congregating in the shelter of any small shrubs or bushes there may be in such country, it seems that the action is largely a controlled one. A clump of hoppers caught in a rainstorm in long grass will disappear entirely from view and will not re-appear again until some time after the rain has ceased, which may be merely a response to a temperature stimulus.

Under normal conditions negative geotropism is strongly exhibited by hopper bands, particularly in the evenings, when they have been observed resting on tree-trunks some 30 feet above ground. Here again the true stimulus may be thermotropic, though the same phenomenon has been observed, to a lesser degree, in bands that have been showing some slight general movement during a normal sunny day.

The phytophilous character of *Nomadacris* hoppers has considerable bearing on their movement. In the younger bands, at any rate, movement under conditions of long jungle grass is not continuous for any length of time. A burst of movement due to some disturbance (apparently even a breath of wind shaking the vegetation is sufficient) will suddenly occur and last for a few minutes, and then the hoppers congregate again on the grass and bushes. In such movement a large proportion of it takes place low down in the grass among the roots, and observation suggested that, on being disturbed, the first hop brings the insect down to the lower parts of the grass where crawling or short hops along the ground are adopted before it again crawls upwards. When paths, roads or bare ground are met with the band may take one of two courses. If the movement of the band is sluggish it will probably remain in the vegetation and continue to move parallel with the obstruction. If, on the other hand, the band is moving forward with considerable impulse it may cross the bare stretch as rapidly as possible, that is, the individuals hop or crawl without cessation and collect in any thick vegetation that is met with at the other side. In the case of the younger bands such movement frequently takes them completely through a clean-weeded maize garden, for example, without much damage being done, whereas in a badly cultivated garden the movement is suppressed and the plants are therefore open to attack. Again and again it was observed that maize gardens full of weeds suffered greater damage from the young hopper bands than did those that were well cultivated. It must not be inferred, however, that a clean garden is free from attack, as it is obvious that the continual movement through such a garden is maintained by the temperature reached by the soil, and the phenomenon was usually noticed during the afternoons and up to 5 p.m. of bright, sunny days. It was unfortunately not possible to obtain accurate records of the temperature at which a hopper band commenced to move, but it appeared that little regular movement occurred before the air-temperature in the sun was 82°F. in the case of young hoppers up to 3rd instar, and with hoppers of this age under the dull weather conditions of January and February 1933 continuous mass movements did not usually occur until after mid-day, when the temperature was in all probability a little higher. Young hoppers were reported on two or three occasions to have been killed by the heat when crossing dry sandy river-beds or bare sandy stretches, but no records of the thermal death point or the time factor were obtainable.

Some observations on the movement of older bands of 4th and 5th (? 6th) instar hoppers at the Port Herald Experimental Station are given in tabular form below. The various plots at this station were bordered with belts of "nsanjre" grass (*Pennisetum purpureum*) in which large numbers of hoppers remained more or less stationary for days on end during early March. Towards the end of the month, in spite of the grass having become already dry and brown, this habit was still noticeable to some degree, but large bands from the jungle began to invade the station. The continual work of driving off the hoppers from the more valuable plots certainly contributed to the scattered nature of the bands all over the experimental station, but the new invading bands were not so disturbed while these observations were made. The station is at an elevation of 150 ft. above sea-level, of flat terrain and close to the Shire River.

Date	Period of movement	Direction	Meteorological readings				Remarks
			Temperature 9.0 a.m.		Per cent. humidity		
			max.	min.	9.0 a.m.	3.0 p.m.	
			°F.	°F.	%	%	
27.iii.33	(morning) to 5.0 p.m.	S. to N.	87·0	73·5	91·0	83·5	Maize attacked
29.iii.33	7.0 a.m. to 5.30 p.m.	E. to W.	90·5	70·5	75·5	60·0	Crawling movement very pronounced unless disturbed
30.iii.33	do.	do.	94·5	70·5	79·0	55·0	do.
31.iii.33 (*a*)	7.0 a.m. to 6.0 p.m.	All directions	91·0	75·0	76·0	65·0	Starting feeding voraciously on sorghums at 6.0 p.m.
do. (*b*)	? to 5.30 p.m.	N. to S.	do.	do.	do.	do.	Outside the station and partly following native paths, crawling
1.iv.35	6.30 a.m. to (evening)	E. to W.	94·0	73·5	76·0	61·0	Crawling movement pronounced

It seems impossible to correlate the direction of movement of the hopper bands with physical features of the ground or any other factors. It was frequently reported that hoppers were following the downward slopes towards depressions or vleis, known locally as "dambos," but such was by no means constant and the very reverse was observed on many occasions. One small band, coming from long jungle grass into short, clumpy grass at the edge of a dambo, changed its direction and moved parallel with the edge of the long grass. Bands that followed the downward slope at first would, after a few days, be found returning up the slope on almost exactly the same line. The one mentioned in the above table [31.iii.33 (*b*)] was the only one in which a very definite crawling movement along native paths was exhibited in any marked degree, and only part of the band (which was a large one) was concerned in this case.

As most hopper bands of *Nomadacris* are of very mixed age, owing to the period over which hatching takes place, ecdysis in any one band is almost a continuous process, and consequently cessation of feeding by an entire band prior to moulting does not occur. Both ecdysis and feeding appear to take place during any hour of the day, though the former was most commonly observed in the early morning and evening. The prosternal peg on the ventral surface between the base of the first pair of legs does not become visible as such until after the first moult, when it appears as a small fleshy protuberance.

The distance travelled by a hopper band in a day is very variable, according to the age of the band, the nature of the country in which it is moving, and the climatic conditions. If an average of 440 yards (¼ mile) and a hopper period of 70 days are assumed, the total distance travelled would be 17½ miles, which most definitely never did occur. Even half this distance would seem to be on the excessive side. During the first three weeks, at least, of the hopper period, movement is almost negligible, hence the difficulty of destroying them by driving at this time. If therefore 50 active days are allowed and ⅛th of a mile a day assumed to be covered, approximately 6 miles would be the distance travelled, which is probably nearer the mark though still somewhat high for many cases.

During 1934 the movement of the bands was, in many cases, practically negligible during the whole of the development to the adult winged stage presumably on account of the wet weather, and in the lake shore area of the Dowa district the phenomenon was observed of scattered hoppers remaining practically quiescent in the jungle grass for weeks on end without making any attempt to form into bands.

Development of Hoppers.

Field observations indicated, though not at all clearly, that growth during the middle period of the hopper life was more rapid than at either the beginning or the end. From specimens bred later in captivity there was found to be a remarkable difference in the length of the early or late and the intermediate instars, as shown in the summary below. The specimens were taken from one batch of egg-packets and all hatched on 17.xii.33. They were all caged in glass jars, 13 by 13 cm., with muslin covers and no moisture extra to the green food was provided. Fifteen of the original 20 specimens survived to the adult stage, all having six instars. Four were raised singly, ten in pairs, and six in threes.

Duration of hopper instars in captivity.

Instar	No. of records	Number of days		
		Average	Minimum	Maximum
1st	20	23·5	22	26
2nd	20	8·7	6	10
3rd	19	8·2	8	9
4th	19	8·6	7	14
5th	18	11·8	8	14
6th	15	20·6	12	24
Total days hatching to flying	19	79·5	64	86

Loss of, or damage to, appendages during the hopper period does not seem to disturb or incommode further development in captivity. Of the specimens used in the work just mentioned, five were damaged as to the legs or antennae after the first moult and two were damaged as to the fore tarsi after the third moult, but all reached the adult stage, whether caged singly or not.

The shortest periods for all the instars after the first were recorded from one individual of a caged pair of females, giving a total time from hatching to flying of 64 days or 15·5 days below the average. Such precocious development appears to occur also among swarms in the field, as occasionally individual hoppers were found that were very much further advanced in development than the majority, being in the 4th or 5th stage when the remainder were only in the 2nd or 3rd stage. In the field the observed periods from hatching to flying correspond reasonably closely with those in captivity, taking into consideration the fact that the latter hoppers would be considerably less active than those in the field. In the summary given above the 19 records of the total time taken between hatching and the final moult include those of four specimens that were bred from 30 hoppers caged all together under similar conditions to the others but of which the moulting records were not kept. The individual periods of these four specimens were 66, 68, 74 and 74 days, or a mean of 9 days below the average of 79·5 days, which appears to indicate that crowded conditions may accelerate development.

Accurate field observations of dates of hatching and flying are, naturally, difficult to obtain. From 13 records, of which the majority are believed to be accurate within two or three days, an average period of 73 days has been computed with a maximum of 89 and a minimum of 65 days. There seems little doubt that the rapidity of development of swarms in the field varies to some extent, but owing to the paucity of meteorological data available it has not been possible to correlate this variation with any particular set of climatic conditions. From the information set out in the table on p. 21 it would appear that the rate of development at the higher altitudes is distinctly slower than at the lower, which have a smaller rainfall and a higher average maximum temperature during the hopper period.

During the 1933–34 season records from the higher altitudes indicated that there was, in many cases, an abnormally prolonged development period.

Whether there had been later egg-laying than was reported, a prolonged incubation period, or whether the development of the hoppers was retarded, it is not easy to state with accuracy, but several instances were observed of the presence of hoppers at an unexpectedly late date. At Lilongwe, recently developed sixth stage hoppers in very considerable numbers were found on 18th May in several swarms of which a fair proportion had already attained wings. In the North Nyasa district sixth stage hoppers were reported in April in places where hatching was known to have occurred before the beginning of February. A hopper band in the second instar was found in the Chiradzulu district on 20th March although flying swarms had developed there earlier in the same month. Careful enquiry produced no evidence that there had been a prolonged incubation period. Late egg-laying (unreported) did undoubtedly occur, but that hopper development was also retarded beyond the normal eight weeks seems decidedly probable. Taking into consideration the fact that, as a result of the prolonged oviposition period, hopper bands of varying ages might quite possibly have become intermingled, in the Lilongwe district in particular, where it was possible to keep hopper bands under reasonably continuous observation, it was found that winged swarms were not formed until early May from hoppers that had hatched in the latter part of January, over 100 days.

Enemies of Hoppers.

Very few predacious insects were found attacking hoppers in the field, neither MANTIDAE nor SPHEGIDAE being recorded. Occasionally species of REDUVIIDAE were observed sucking first stage hoppers. On the Palombe Plain, where this insect abounds, two specimens of the Tettigoniid, *Acanthoplus speiseri*, Brancs., were taken in March 1934 devouring fourth stage hoppers.

Climatic Conditions and Period of Development from Hatching to Flying, 1933.

Place and altitude	Total rainfall Jan.–April		Mean monthly humidity and degree of wetness				Average temperatures in °F., (1) maximum, (2) mean				Observed development in days	Remarks
	Ins.	Days	Jan.	Feb.	March	April	Jan.	Feb.	March	April		
1. Fort Manning, 4,228 ft.	22·09	48	— 10·8	— 7·2	— 10·4	— 1·1	(1) 74 —	76·5 —	76·4 —	77 —	(*a*) 80 (*b*) 77–85	Probably in full flight; record (*b*) the more accurate.
2. Likuni, 3,600 ft.	18·96	48	69·5% (9.0 a.m. readings only) 9·5	52·5% 14·3	49% 3·3	40% 0·3	(1) — (2) —	78 72	77 71	77 69	85	Probably in full flight.
3. Namitete (Muwanga), 3,300 ft.	16·14 (Jan.–March)	38	— 4·0	— 8·8	— 8·0	— —	— —	— —	— —	— —	89	Full flight; probably less; conditions very similar to 1 and 2.
4. Nkwale, 1,800 ft.	22·52	58	81% 16·9	89% (Probably too high) 19·5	78·75% 8·3	72% 0	(1) 83 (2) 76	83 73	84 75	84 73	65	First fliers; area near lake shore; accurate.
5. Bwanje, 2,000 ft.	14·15 (Jan.–March)	37	— 8·0	— 7·6	— 2·6	— —	(1) 83 (2) 73	84 76	— —	— —	— 74	Inland area; fairly accurate.
6. Fort Johnston, 1,550 ft.	17·32	43	65·5% (av. 9·0 a.m. / 3.0 p.m. readings) 10·9	61·92% 17·7	59·88% 2·8	56·8% 0·1	(1) 86 (2) 73	89·6 69·7	90 70	88 67	(*a*) 64 (*b*) 68	Near lake shore; (*a*) first fliers, (*b*) full flight.
7. Liwonde, 1,500 ft.	12·82	34	— 4·3	— 5·3	— 1·1	— 1·3	(1) 84 (2) 70	84 69	88 72·5	85 67·5	(*a*) 63 (*b*) 68	(*a*) first fliers, (*b*) full flight; accurate record.
8. Utale, 1,500 ft.											68	Conditions almost identical with 7; accurate record.
9. Chikwawa, 500 ft. ?	13·45	20	— 3·2	— 4·2	— 0·2	— 0·6	(1) 89 (2) 76	90 74	91 74	90 73	70	Swarm probably developed in the foothills.
10. Chiromo (Nyapambere), 150 ft.	12·22	31	72·8% (av. 9.0 a.m. / 3.0 p.m. readings) 3·8	79·6% 4·5	73% 0·3	70·2% 2·1	(1) 91 (2) 84	90 82	92 83	88 79	67–68	Close to Shire River; accurate record.

Birds were not a great deal in evidence among hopper bands, though storks, possibly assisted by bee-eaters and starlings, were recorded on one occasion in the South Nyasa district as destroying, fairly completely, a small-sized band.

Parasitic worms (MERMITHIDAE) were not observed in hoppers, but as they were found in some of the first developed adults in 1933, it is possible that they were present.

Parasitism by SARCOPHAGIDAE or TACHINIDAE did not develop to any noticeable extent until late in the 1933-34 hopper period, but by March 1934 infestation of both hoppers and adults by these parasitic Diptera was being reported from nearly all the infected areas on a considerable scale. By this time also the fungus disease (*Empusa grylli*) had developed to a high degree of effectiveness, and both species of parasites were bred from diseased hoppers, the disease being apparently secondary to the parasitism.

Adult Swarms.

The earliest flights of a *Nomadacris* swarm might be described as a " drifting " movement over the tops of the trees, along the sides of the hills and up and down the gulleys and ravines, the swarm thinning out and closing up, part settling for a short time and then starting to fly again. Flights over the plains, or the later flights as the rains approached, which presumably would be the true migrating flights, were more purposeful and directive. But even in these cases the density of the swarms was extremely variable and the vertical range would extend from a few feet above ground to a very considerable height. In these later flights the height of the upper limits of a swarm was a very marked feature, and frequently against a clear blue sky the swarm would be quite invisible unless viewed directly against the sun. For this reason coupled with the apparent " looseness " of a swarm flying at height, it would be quite possible for a large swarm to pass overhead without being observed at all. The total distance travelled by a swarm in a day is very variable. Accurate observations on sexually immature swarms gave distances varying from 2 to 10 miles, and one swarm followed for five days travelled 7, 7, 10, 5 and 6 miles each day. The true migratory flights are, of course, much longer and may apparently cover some 60 miles or even exceed this figure. Flying after dusk and until quite a late hour on moonlight nights was reliably recorded on several occasions, but no observations of temperature or humidity are available for these cases.

When taking off the ground or a low object, the locusts appear to direct themselves against the wind and at a height of a few feet turn completely round. Generally a swarm proceeds across the wind rather than directly with it, though directly against a light breeze, and the reverse with strong winds have been observed.

Temporary cessation of flight of the whole, or part, of a swarm during the hottest period of the day was a common occurrence, but the irregularity of such a proceeding rendered it difficult to establish the influence causing it, as frequently a change in direction or strength of the wind would appear to be sufficient to produce such a result in a swarm not in strong flight.

Field observations at Port Herald (150 ft. elevation) indicated that the swarms did not commence to fly until the shade temperature had reached 80°F. On one dull day in April a swarm did not begin to rise from the plants on which they were roosting until about noon, when the shade temperature was 82°F. and the humidity 77 per cent. The first signs of activity displayed by a roosting swarm is a rapid vibration of the wings. This occurs, to begin with, among a few individuals, but the number performing the action increases until trees or bushes completely covered with locusts, or whole areas of a swarm, are one glinting, shimmering mass, impossible to describe. This is followed by a drifting movement from the trees to the ground, the individual insects appearing merely to release their hold and glide downwards with wings outstretched but not moved as in flying. More or less concurrently with such movement it will be found that the insects are easily disturbed but will not move (except for the drifting action mentioned) *unless* disturbed. A little later indecisive swirling flight accompanied by much settling begins, which continues frequently for a considerable time, and may be brought to a rapid cessation by a change of wind or obscuring of the sun by clouds. Later still the definite flight, usually audible, begins and towards the middle of the day the high flying movement, mentioned above, sets in. Naturally the variation in these movements is considerable, and disturbance of a roosting swarm just at sunrise, by natives collecting them for food for example, seems also to cause the wing vibration movement to be performed as well as definite flighting away from the disturbance.

At times it seemed as though the movements of swarms at the beginning of flights and when about to settle for the night were influenced by the angle at which the sun was shining on them, but no valid observations could be made on this point.

The phenomenon of wing vibration is not apparently confined to early morning and evening, as it was also observed among a few stragglers from a swarm resting on the ground in the late afternoon on at least one occasion, when temperature and humidity records were not possible. It was found that it was possible to get closer in the evening than in the morning to individuals that were performing this act, without disturbing them. The action is accompanied by a wriggling motion of the entire abdomen, usually lateral, but sometimes vertical or a combination of the two. Frequently, though not invariably, there is also an extension and retraction of the head from the thorax, straight forward from and straight back to the pronotum. Usually the hind pair of legs are not used for grasping the resting perch, but are folded with the tibiae and tarsi forward immediately below the femora which are directed backwards along the sides of the abdomen. On occasion it appeared that the hind femora, if not the whole leg, were shaking as well, but this may have been due to actual contact with the anal angle of the vibrating hind-wing. One individual was timed to carry out this movement for two minutes without ceasing.

Parasitism of the sexually immature adults by Mermithid worms was observed in the Lower Shire district as soon as the flying swarms developed, and this parasitism was to be met with to a small extent throughout the dry season of 1933. No reports of swarms being decimated by the worms were made, but early in October large numbers of locusts died suddenly in one swarm in the Cholo district. Unfortunately the occurrence was not at once notified, and when investigation was made ants had so destroyed the dead locusts that it was impossible to express an opinion as to the cause of death. It was certainly not fungus disease, nor was it normal death after egg-laying.

Parasitism by SARCOPHAGIDAE and TACHINIDAE was very slight, on the whole, during 1933, but as was the case with the hoppers, this form of natural control, as well as infection by nematode worms, rapidly increased among the swarms developing in the early months of 1934 and continued throughout the year.

Seasonal Movements of Swarms.

When adults of the seventh generation began to develop in various parts of the Protectorate in April 1933, it soon became evident that the lower elevations, below 2,000 feet, were being vacated by the swarms which were tending to concentrate in the hills. As the dry season, May to October, continued certain areas below this altitude became entirely free from swarms for periods varying from one to six months, or if swarms appeared in these districts they passed through them by sustained flight and did not remain there as they did in the higher elevations making daily circular flights. With the approach of the rainy season, beginning in November, the lower elevations were re-invaded by swarms from the hills. Although in certain instances it appeared that the prevailing wind might have had considerable influence on such movement, it could not by itself satisfactorily explain this very pronounced phenomenon in every case.

Comparison of the swarm movements with the dry and wet season rainfalls indicated broadly a possible reason for the change in distribution of the swarms during the two seasons. The areas vacated completely and for the longest time were those having a rainfall of less than 0·10 inch in the period 1st May to 31st October. The larger part of the central and southern districts of the Protectorate have a rainfall during this period of between 0·10 and 2·50 inches, there are smaller belts of from 2·50 to 5·00 inches with increasing rainfall at a few isolated places, and there was a distinct tendency for the swarms to concentrate in these areas having this greater amount. The concentrations during the dry season were thus found largely in the hills to the west of Fort Manning and Kasungu districts, the Dzalanyama range south-west of Lilongwe, the Namwera hills east of Fort Johnston, the Kirk Range west of Neno, Zomba and Mlanje Mountains, the hills dividing the Shire valley from the Blantyre and Cholo districts, possibly in the various ranges to the west of the Lower Shire district and certainly in the vicinity of Chiperone and Derre Mountains in Portuguese territory to the east of that district.

During the breeding season the swarms were massed in those areas having a rainfall up to 35 inches between 1st November and 30th April. Although in the 1933–34 season egg-laying and hopper development took place in areas with a rainfall up to 50 inches in this period, the manner in which the swarms moved easterly across central Nyasaland, from the north-eastern Rhodesian border to the lake shore, *in both seasons*, following the 30–35 inch rain belt was most marked.

In 1934 swarms of the eighth generation developed during March and April, somewhat earlier than in the previous year, and the continuation of the rains into the normally dry months rendered the movement of these swarms considerably more difficult to follow than previously, not only by equalising the conditions between the plains and the hills, but also by influencing the swarms to remain practically quiescent for considerable periods. Nevertheless the same tendency to vacate the extreme low levels was apparent to a considerable extent and some areas again remained free from swarms for the greater part of the dry season. The return flight as the rains approached tended to duplicate those of the previous year, being most marked again from west to east, across central Nyasaland to the lake shore.

From these observations it appeared possible that humidity might be, at least, one factor influencing the movement of swarms during the dry season. The areas vacated by the swarms, being of low altitude, also have a mean maximum temperature that rarely falls below 80°F. in any month. Unfortunately meteorological records that include humidity are very scarce in Nyasaland and only eleven records suitable for comparison one with another are available. These records include two stations (Zomba, 2 years; Mlanje, 1 year) at the higher altitude where swarms remained in circling flight during nearly the whole of the dry season, and four stations (Salima, Nkwale, Fort Johnston, Port Herald, 2 years each) at the lower altitudes which swarms generally vacated.

The climatographs for these stations drawn for mean maximum temperature and mean relative humidity (9.0 a.m. and 3.0 p.m. daily readings) produce some interesting data.

Zomba, 2,500 feet. In the vicinity of Zomba mountain; surrounding country all above 2,000 feet and with many isolated hills. Rainfall reaching 7·50 inches in the dry season.

FIG. 1. ZOMBA 1933.

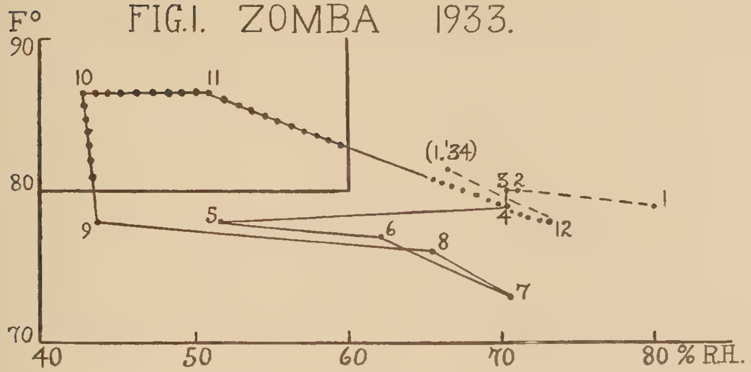


FIG. 2. ZOMBA 1934.

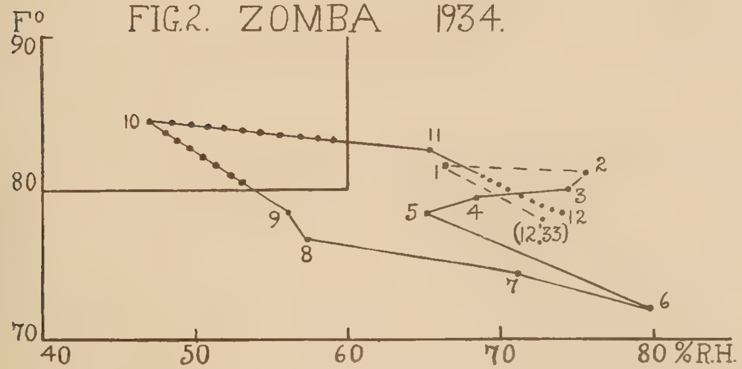
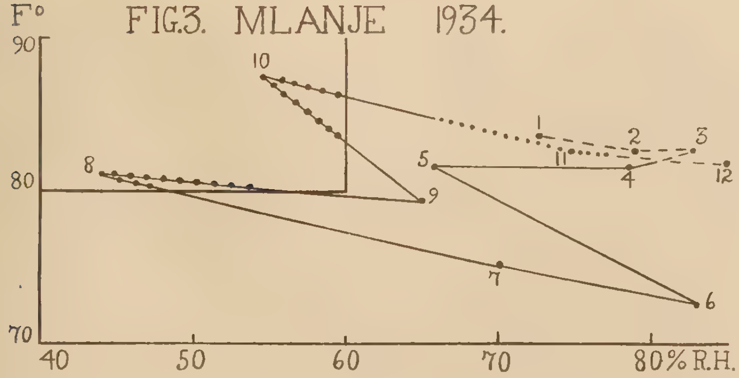


FIG. 3. MLANJE 1934.



······ = EGGS. ——— = ADULTS, MAINLY CIRCLING FLIGHT.

– – – – = HOPPERS. —•—•—•— = ADULTS, MAINLY SUSTAINED FLIGHT, WHEN PRESENT.

(THIS LEGEND APPLIES TO ALL FIGURES.)

(*a*) 1933 (fig. 1). Adults of the seventh generation began to appear about 24th April. From that time until the end of September the maximum temperature did not reach 80°F., only in May and September did the relative humidity fall below 60 per cent., and swarms were circling continuously round the lower slopes of Zomba Mountain. In October and November the temperature reached 86·5°F. in each month, the relative humidity fell to 43 and 51 per cent. respectively, and in both these months sustained flights took place taking the swarms away from the mountain-side.

(*b*) 1934 (fig. 2). A similar movement occurred. Adults of the eighth generation appeared first on 28th March, and flights continued to circle at the base of the mountain for the next six months, the humidity from April to July being above 65 per cent. (slightly higher on the whole than in 1933) and the temperature not rising above 80°F. until the beginning of October. Although two small sustained flights occurred in August and one in September when conditions were changed by a marked fall in humidity and a slight rise in temperature, flights of magnitude lasting for several days on end did not occur until 21st–30th October and 25th–30th November, which were the only two months in the year when the temperature was above 80°F. and the relative humidity below 60 per cent. simultaneously.

Mlanje, 2,300 feet. On the south-east slopes of Mlanje Mountain having a high rainfall, which may be over 10·0 inches in the dry season. One year's record only available.

(*a*) 1934 (fig. 3). This area was practically never free from swarms during the whole year, and only for two short periods, late August to early September and the latter half of October and early November, did the temperature rise above 80°F. and the relative humidity fall below 60 per cent. at one and the same time.

Salima, 1,669 feet and *Nkwale*, 1,800 feet. These two stations can be taken together as they lie within a few miles of one another at 13°40[1]S., Salima in the lake shore plain and Nkwale at a slightly higher elevation to the west, nearer the hills. This area is one having only 0·10 inches of rain in the dry season and was completely vacated by locust swarms, the direction of flight being west and north-west and conforming fairly consistently with the prevailing wind, which at that time of the year is of considerable strength from the south-east.

(*a*) 1933 (figs. 4 and 5). Adults of the seventh generation were observed flying on 16th April at Nkwale and a strong westerly movement was maintained throughout May, by the end of which the area was reported clear. No flying swarms were observed again until 12th December when return flights reached Nkwale from the west. At both stations, from the middle of April until November the relative humidity was below 60 per cent. (generally below 55 per cent.) and the temperature was above 80°F., with the one exception of July at Nkwale when it dropped to 79°F.

(*b*) 1934 (figs. 6 and 7). The movement was repeated. Adults of the eighth generation moved away in a westerly direction during April and May, the district again being reported clear of swarms from the middle of May until 28th November, when return flights from the west began to arrive and continued throughout December. In this year the temperature at Nkwale in June and July, by which time no swarms were left in the area, was 77 and 79°F. respectively, the only records below 80°F. for the two stations, and all humidity records for this period were below 60 per cent.

Fort Johnston, 1,550 feet. At lake level at the southern end of the lake. High land rises to the east and north-east and also a hill from the plain to the west, both reaching more than 4,000 feet altitude. Thus the station lies in a somewhat narrow plain, banded on two sides by hills, to the north by the lake and to the south by a considerable expanse of water, Lake Malambe. Dry season rainfall not exceeding 2·50 inches.

FIG.4. NKWALE 1933.

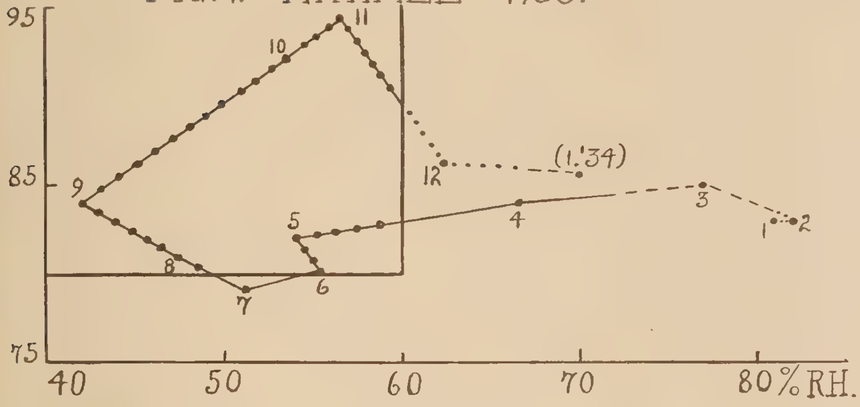


FIG.5. SALIMA 1933.

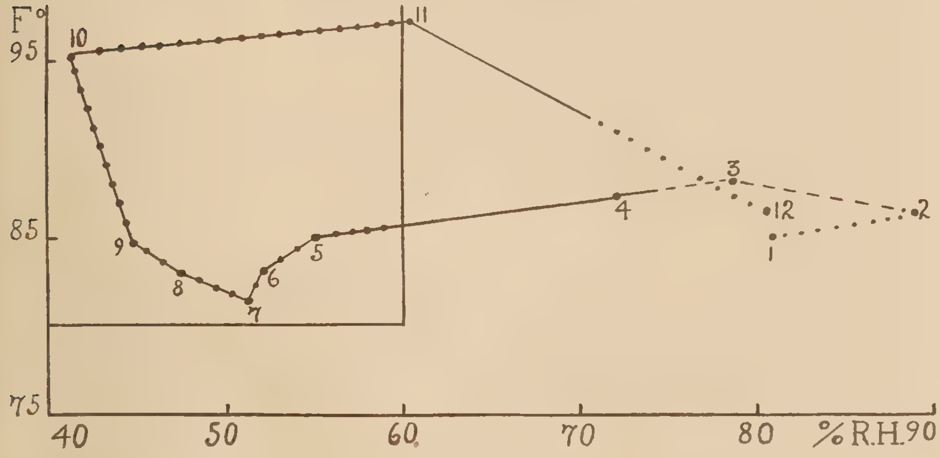
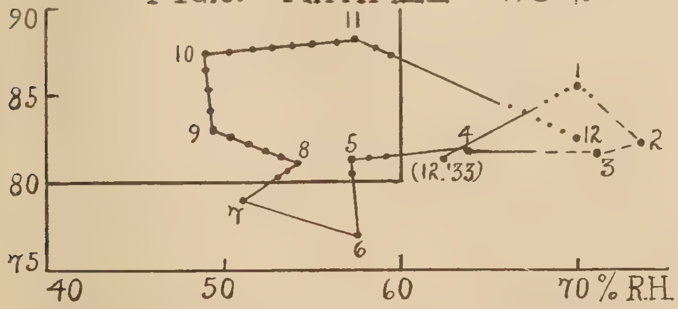


FIG.6. NKWALE 1934.



(*a*) 1933 (fig. 8). These records are not so well defined as those already quoted or as those for this station in 1934. The area was exceptionally heavily invaded by the original swarms of the sixth generation and daughter swarms were intensely numerous in the surrounding country. At this station the temperature was never below 80°F. for the whole year and the humidity had dropped below 60 per cent. by the end of March, not rising above this figure until after November. As the seventh generation did not begin to fly here until towards the end of April, the climatic conditions that at Salima and Nkwale coincided with an absence of swarms were already in existence when the flying swarms developed. The immediate tendency of these swarms was to move into the hills, mainly to the north-east, and though swarms were recorded at this station up to July, they were continuously on the move and not making circling flights as in Zomba or Mlanje. Their presence can partly be accounted for by the large number of swarms that were present in the neighbourhood. No swarms were recorded in August, and though sustained flights occurred again in October and November, swarms did not remain in the vicinity of the station until December.

(*b*) 1934 (fig. 9). Adults of the eighth generation appeared first on 23rd February, the humidity conditions from then until the end of April being very different from those obtaining in the previous year. From May until the middle of November, when the temperature was more than 80°F. and the relative humidity below 60 per cent., the station was clear of swarms, which had again concentrated mainly in the hills to the north-east.

Port Herald, 500 feet. On the Shire River at the southern end of the Protectorate, with a small range of low hills to the west but otherwise surrounded by a fairly extensive plain that rises to more than 2,000 feet with isolated higher hills (Chiperone and Derre) in Portuguese territory to the east. The dry season rainfall may reach 5·00 inches, and though the temperature was well above 80°F. in both years, river mists may affect the humidity recorded at the station.

(*a*) 1933 (fig. 10). Adults of the seventh generation began flying towards the end of March and swarms were continuously in the district until August, though showing a tendency to move north-east into Portuguese territory. During this period though the relative humidity was above 60 per cent. the temperature was well above 80°F. During September and October the station was reported clear of swarms and only a direct flight from west to east took place in November, the three months when the humidity was below 60 per cent., the temperature remaining above 80°F. Re-invasion by swarms that remained at the station occurred in December.

(*b*) 1934 (fig. 11). This is the only set of records in the series that shows any wide discrepancy from the others. Adults of the eighth generation began to develop early in February and circling flights continued until May. During April and May there was a tendency for the swarms to move north and north-west, contrary to what occurred in 1933. This seemed to clear the swarms away from the station, which was reported to be free during June and July, although the relative humidity was well above 60 per cent. during these two months. The temperature was continuously above 80°F., however. In August and September, when the relative humidity had fallen considerably, the district was also clear except for two sustained flights in a north-westerly direction. A similar sustained flight occurred in October, but also in this month a certain proportion of circling flight took place which increased in November and December.

Climatographs representing other combinations of climatic factors (maximum and minimum temperature and rainfall and monthly degree of wetness, minimum temperature and relative humidity) have been studied for the same stations but

FIG.7. SALIMA 1934.

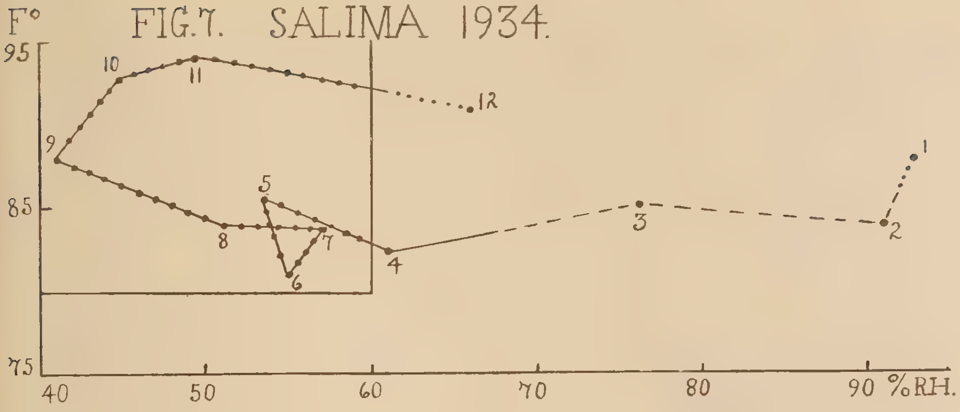


FIG.8. FORT JOHNSTON 1933.

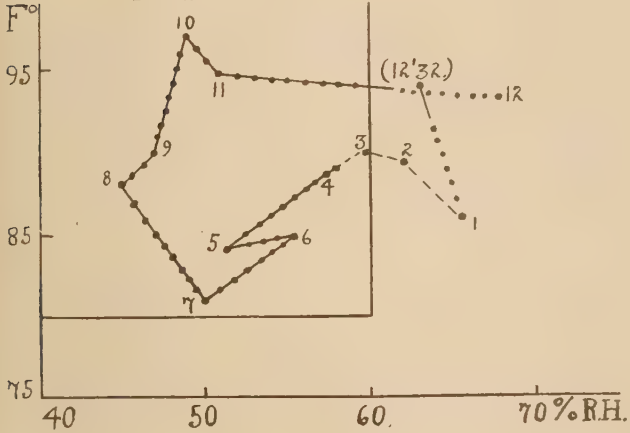
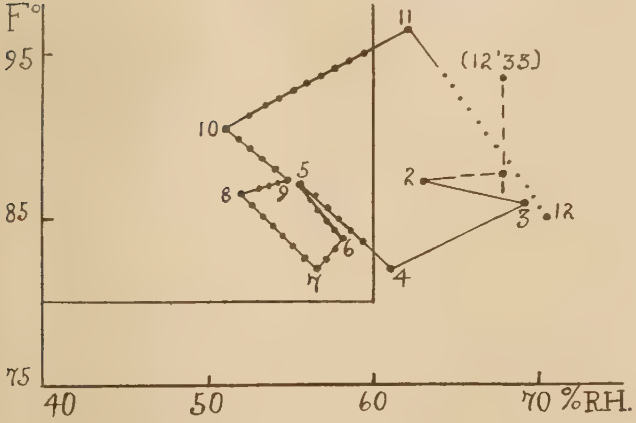


FIG.9. FORT JOHNSTON 1934.



none gives such an apparent correlation between the wet and dry season conditions and the movement of flying swarms. Climatographs representing the factors of maximum temperature and relative humidity for the years 1931 and 1932 at Zomba and Port Herald are very similar to those of 1933 and 1934, so that these latter years are not in any great degree abnormal. Indeed the climatograph for these conditions at Zomba in 1898, during the previous *Nomadacris* invasion and when, as it appears from the available records, Zomba was continuously inhabited by swarms, shows that during the month of October alone did the temperature rise above 80°F. with a relative humidity below 60 per cent. (fig. 12).

To obtain sharply defined limits of the climatic factors controlling flight of *Nomadacris* swarms would require a greater series of meteorological stations than is possible in Nyasaland, but so far as the present observations go they indicate, broadly, that the coincidence of a maximum temperature above 80°F. and a relative humidity below 60 per cent. provides conditions which, if not completely unsuitable for flying swarms, at any rate stimulate sustained flight as opposed to the indefinite circling flight adopted by swarms that remain in areas where these climatic conditions do not occur simultaneously.

It was not possible to obtain data showing whether the reaction of a swarm to the climatic factors involved was in any way influenced by the age of the swarm. It is perhaps worth noting, however, that with few exceptions the return flights to those areas that had been vacated coincided with a rise in humidity to the region of, or above, 60 per cent. If the humidity was below this figure in November, when the first indications of the return movement were usually noticeable, there was invariably a rapid rise in December accompanied by a fall in temperature. At the four stations that were vacated the average increase in humidity from the beginning of November to the end of December for the two seasons was 20 per cent.

It is not suggested that these two factors and no others control the movement of flying swarms. It is apparent that the movement of a swarm must be influenced to some extent by the physical features of the country over which it passes, unless it is flying at such a height that it will avoid all normal variations of the land surface, when presumably it will be subject to different conditions from those obtaining at ground-level. Apart altogether from climatic factors, a plain with numbers of isolated hills rising abruptly from it with which swarms are bound to come in contact must produce more irregular movements than a continuous stretch of unvarying altitude lacking any pronounced physical features.

Although these observations on the seasonal movements of the swarms refer to the southern half of the Protectorate, from latitude 13°S., the general trend of the information from the less populated northern half, where meteorological records are even more scanty and continuous observations were not possible, indicated that the movement there was reasonably comparable with that in the south. But the physical features of the northern part of the Protectorate would not seem to offer the possibility of the same clear-cut movement taking place.

The difference in rainfall between the two years at the stations referred to was as follows :—

Station ...	Zomba		Mlanje		Nkwale		Salima		Fort Johnston		Port Herald	
Year ...	1933	1934	1933	1934	1933	1934	1933	1934	1933	1934	1933	1934
Inches rainfall	41·29	49·97	—	72·7	27	38·26	26·58	49·67	25·16	37·03	24·86	33·98

FIG. 10. PORT HERALD 1933.

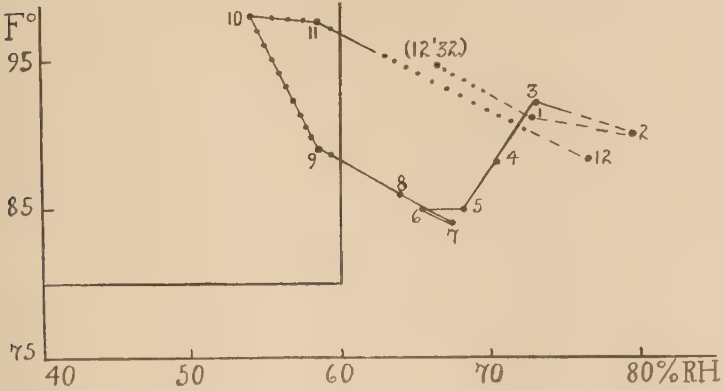


FIG. 11. PORT HERALD 1934.

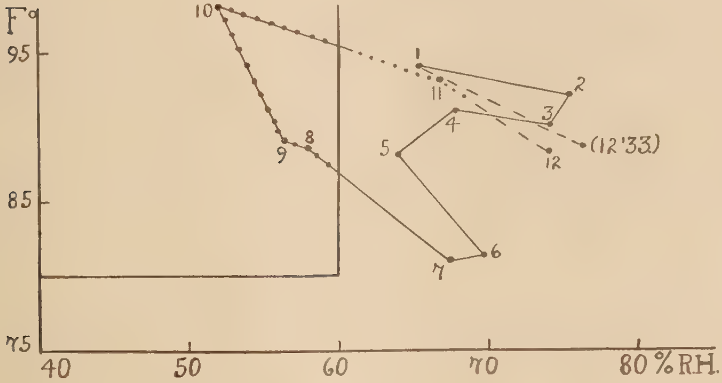
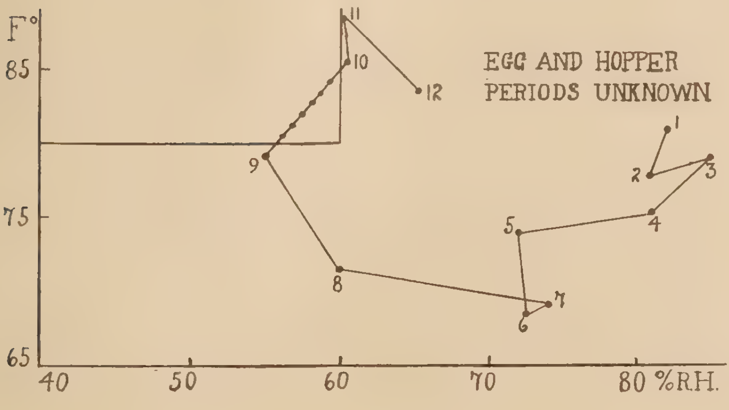


FIG. 12. ZOMBA 1898.



The Fungus Disease, Empusa grylli, Fres.

The disease was first noticed in a small swarm of 2nd instar hoppers in the Bwanje Valley on 12th February 1934. From then onwards its presence was reported in every area of the Northern Province, and later it developed throughout almost the whole of the Protectorate, with the possible exception of the Lower Shire district. It was particularly effective in the Northern Province during February and March owing to the weather conditions being very suitable for its development and spread. A few empirical attempts were made to distribute the disease, but it was almost impossible to find a swarm in which the fungus was not present to some degree. Later, when the disease was studied more closely with the assistance of the Mycologist, it was realised that these attempts had been quite useless as the material used, dead hoppers on grass stalks collected during the day, carried practically no fungus spores. It was found that sporulation occurred late in the evening and during the night, and the diseased insects rapidly dried up the following morning. Consequently to obtain a quantity of the fungus spores it is necessary to collect the dying hoppers that show no external sign of the disease, in the evening, and keep them enclosed during the night. But that it is impossible to accomplish any increase in the disease by spraying a suspension of spores over a swarm, appears to be proved rather conclusively by the following experiments carried out by the Mycologist.

To determine the natural spore distribution in the field, agar-covered glass slips were placed at various heights among or in the vicinity of hopper swarms for a night and the number of spores per square centimetre collected on them counted next morning.

A. Slides horizontal, among newly-killed hoppers. No living insects near at hand. Three different areas for three sets of slides. Heavy rain 7.30 p.m., then fine.

Position of slides in grass	Number of spores per sq. cm.			
	Series 1	Series 2	Series 3	Average
Top	214	216	308	246
Middle	338	124	315	259
Base (1 ft. from ground)	126	62	82	57

B. Slides horizontal, in middle of swarm settled for night, about 30 yards from position A. Three different areas for three sets of slides. Heavy rain 7.30 p.m., then fine.

Position of slides in grass	Number of spores per sq. cm.			
	Series 1	Series 2	Series 3	Average
Top	6	7	45	19
Middle	4	2	46	17
Base (1 ft. from ground)	3	9	23	12

C. Slides horizontal, in middle of small swarm settled for the night. Two different areas for two sets of slides. Light rain 4.0 p.m., then fine.

Position of slides in grass	Number of spores per sq. cm.		
	Series 1	Series 2	Average
Top	5	15	10
Middle	8	5	7
Base (1 ft. from ground)	3	7	5

Spraying with a suspension of spores over similar slides was carried out as follows :—

(i) 100 diseased hoppers that had not spored collected in the evening and kept in an empty petrol tin overnight. Spore suspension made at 7.0 a.m. next morning ; $\frac{1}{4}$ gallon of water poured into the tin, well stirred, and then made up to 4 gallons with water. Spray made from Four Oaks Knapsack sprayer over slides placed horizontally, 3 yards from each other ; 6 slides at 2 yards from nozzle = Heavy spray (D) ; 6 slides at 4 yards from nozzle = Light spray (E).

Slide No.	Number of spores per sq. cm.	
	D. Heavy spray	E. Light spray
1	32	14
2	32	7
3	21	21
4	19	7
5	17	8
6	19	11
Average	23	11

(ii) The above suspension in the machine diluted with an equal quantity of water. Six slides placed horizontally on the ground distributed over approximately 30 square yards. Spray not directed straight at the slides, but contents of machine sprayed over the whole area.

No. of slide	1	2	3	4	5	6	Average
Number of spores per sq. cm.	3	6	4	7	1	9	5

This would more nearly approach the results that would be obtained if spraying a spore suspension over a hopper band was resorted to, rather than where the spray was directed straight at the slides.

From the average figures in the above tables, comparison between natural and artificial spore distribution gives the following numbers of spores per square centimetre :—

Natural spore distribution			Spore distribution by spraying suspension obtained from 100 hoppers		
Outside swarm but in area of diseased hoppers	In hopper band		Direct spray		General spray
A	B	C	Heavy D	Light D	
187	16	7	23	11	5

Therefore to obtain by artificial means any effective increase over the natural infection, assuming that this is really as indicated by the above figures, an extremely large number of diseased insects would have to be collected on each occasion.

A comparison of the rainfall in various areas for the two hopper periods shows the reason for the development of the fungus in one season and not the other. In 1933 hatching was general at the end of January and the beginning of February, but in the next season it commenced in some places about the middle of December and continued through January, and it appeared that, under the then existing climatic conditions, less than two months was required for the fungus to become generally noticeable. The tables below compare the total rainfall in inches and number of rainy days (columns A and B respectively) for the three months after hatching in 1933, *when no disease appeared*, with similar figures for the period of the 1933/34 hopper season in which the fungus developed.

Area 1 Port Herald, 150 ft.				Area 2 Fort Johnston, 1,700 ft.				Area 3 Balaka Station, 2,000 ft.			
1933 Feb.-April		1933–34 Dec.–Feb.		1933 Feb.–April		1933–34 Dec.–Feb.		1933 Feb.–April		1933–34 Dec.–Jan.	
A	B	A	B	A	B	A	B	A	B	A	B
8·22	21	19·44	29	11·28	25	18·03	43	10·21	24	19·02	28
		Very slight disease in hills early in March				Disease in early March				Disease by 12th February	

Area 4 Fort Manning, 4,228 ft.				Area 5 Likuni, 3,600 ft.				Area 6 Salima, 1,669 ft.			
1933 Feb.–April		1934 Jan.–Feb.		1933 Feb.–April		1934 Jan.–Feb.		1933 Feb.–April		1934 Jan.–Feb.	
A	B	A	B	A	B	A	B	A	B	A	B
15·74	31	20·86	37	11·04	36	17·99	41	16·79	25	22·85	38
		Disease before 19th February				Disease before 19th February				Disease before 20th February	

In these records the minimum rainfall when the disease developed was about 18 ins. (41 days) during two months (Area 5), the succeeding month being also very wet, and the maximum which did not influence the development of the fungus was 16·79 ins. (25 days) during three months, the third of which was rainless (Area 6). In the case of Area 4 in 1933, the third month had only 2·25 ins. of rain on 5 days. In these two latter cases, however, hopper development had practically ceased by the end of April.

Four records of the rainfall during the actual period from hatching to the date when the disease was first reported are as follows :—

Near Area 3 Mitongwe		Area 4		Area 5		Area 6	
A	B	A	B	A	B	A	B
14·81	33	15·58	30	14·28	32	15·77	25

These records are similar to those obtained by Skaife (1925) in South-west Africa, but apparently about 15 ins. of rain in some 30 days out of a 60-day period was sufficient, under local conditions, to start the disease as a controlling factor.

In the field the disease appeared to attack hoppers in all stages after the first instar and to some extent the adults as well, though in general by the time the adults have developed the local climatic conditions are no longer suitable for the further growth of the fungus. There is no doubt that the disease was responsible for reducing the size of the hopper bands to a very considerable extent during the 1933–34 period. During 1934, owing to the unusual rainfall the disease continued to function spasmodically among the flying swarms during the winter months, but towards the end of the year it was recorded in some places that destruction on a large scale was again taking place, though possibly some oviposition had already been made by the locusts thus killed.

Apart from the fungus disease taking a heavy toll of the hoppers in most districts, there were definite records of some bands failing *entirely* to reach the adult stage. This occurred in two places in the north-west corner and three places on the lake shore of the North Nyasa district, in four places on the western side of Mombera district, and on the lake littoral of the Chintechi district. In the latter case only are meteorological records available for the actual situation where such wholesale natural destruction took place. For the three months January to March 1934, when hopper bands were present, the total precipitation was 29·92 ins. over 44 days, and if the April rainfall, which occurred mainly in the first three weeks of the month, be added the high total of 48·08 ins. over 62 days is obtained. Although this figure is 10·05 ins. greater than the corresponding period of the previous year (60 days), the difference in mean monthly temperatures was very slight, the average of the four months' means being 73·3°F. in 1934 and 75·25°F. in 1933.

References.

SKAIFE, S. H. (1925). The locust fungus, *Empusa grylli*, and its effects on its host.—S. Afr. J. Sci. **22,** pp. 298–308, 1 pl.

SMEE, C. (1934). Report of the Entomologist.—Ann. Rep. Dept. Agric. Nyasaland 1933, pp. 46–53.

——. (1935). Report of the Entomologist.—Ann. Rep. Dept. Agric. Nyasaland 1934, pp. 16–18.

UVAROV, B. P. (1933). The locust outbreak in Africa and western Asia in 1932.—Economic Advisory Council, Committee on Locust Control, London, H.M.S.O., 63–80–2, 74 pp., 11 maps.

THE OUTBREAK CENTRES OF *SCHISTOCERCA GREGARIA*, FORSK., ON THE RED SEA COAST OF THE SUDAN.

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(Plates I & II.)

The existence of outbreak areas of the desert locust on the Red Sea Coast was first discovered by H. B. Johnston (1926) during the winter of 1925–26. The author of the present paper has visited the Red Sea Coast every winter since 1929–30, and has travelled in this area from near Massawa in the south to the neighbourhood of the Egyptian boundary in the north. The present paper deals mainly with observations made from December 1933 to May 1934, and with more detailed work carried out from November 1934 to March 1935.

Description of Red Sea Coast (fig. 1).

The coastal plain of the Sudan varies in width from 8 to 20 miles. It is bounded on the east by the sea and on the west gradually rises up to the foot of a range of rocky mountains which runs for some distance inland. These mountains are lower in the north and higher in the south towards Eritrea. Although the northern peaks may reach a height of 6,000 ft., there is little high land among them. Here also the mountains themselves bear practically no vegetation except in the case of Jebel Elba which is exceptionally near to the sea.

Among the hills the vegetation is largely confined to the beds of khors (or small rivers) which flood for a short period only after rain. This vegetation consists mostly of the bushes *Salvadora persica*, Linn., *Lycium persicum*, Linn., and *Leptadenia spartium*, Wight., and the tussock grass *Panicum turgidum*, Forsk. In the more westerly khors the large *Acacia albida*, Del., is common in the north.

The khors are stony in their upper and sandy in their lower reaches. Most of those which rise in the eastern hills flow across the coastal plain into the Red Sea, while those which have a westerly origin lose themselves, for the most part, in the desert plain between the hills and the Nile. This plain consists largely of hard sand mixed with clay and gravel, which gives way to clay in the south and loose, blown sand in the north. It has not been travelled over extensively by the writer, but in the neighbourhood of Gebeit Mine, where the hills open out, the main perennial vegetation consisted of scattered *Acacia tortilis*, Hayne, *A. ehrenbergiana*, Hayne, with some *Balanites aegyptiaca*, Del., with the undershrubs *Aerva tomentosa*, Forsk., and *Fagonia cretica*, Linn., and the perennial grasses *Panicum turgidum*, *Lasiurus hirsutus*, Boiss., and *Cymbopogon* sp. The annual vegetation was withered when this area was visited, but consisted mostly of grasses (*Aristida* spp.), which occurred in patches, or singly with a large amount of bare ground between them.

The Coastal Plain.

The coastal plain may be divided roughly into four strips running north and south of which the plant associations seem to be determined by soil differences.

The western strip adjoining the foothills is in places very stony and bears practically no vegetation except in the deep khors. For the most part, however, the soil of

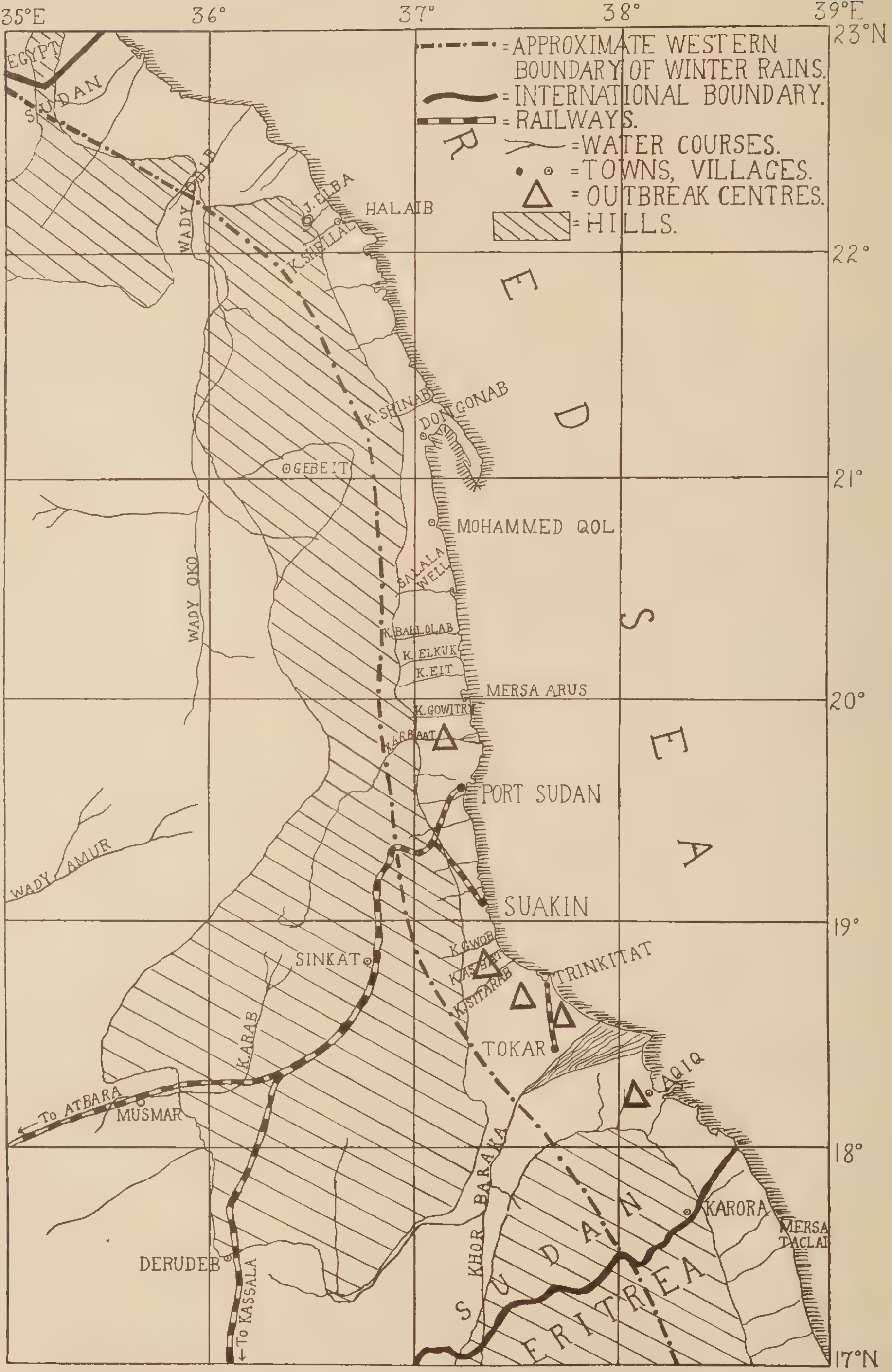

35°E
36°
37°
38°
39°E
23°N
22°
21°
20°
19°
18°
17°N
= APPROXIMATE WESTERN BOUNDARY OF WINTER RAINS.
= INTERNATIONAL BOUNDARY.
= RAILWAYS.
= WATER COURSES.
= TOWNS, VILLAGES.
= OUTBREAK CENTRES.
= HILLS.
EGYPT
SUDAN
WADY ODIB
J. ELBA
K. SHELLAL
HALAIB
RED SEA
K. SHINAB
DONGONAB
OGEBEIT
MOHAMMED QOL
SALALA WELL
WADY OKO
K. BALLOLAB
K. ELKUK
K. EIT
MERSA ARUS
K. GOWITRI
K. ARBAAT
PORT SUDAN
WADY AMUR
SUAKIN
SINKAT
K. GWOB
K. ASHAT
K. SITARAB
TRINKITAT
TOKAR
KARAB
AQIQ
To ATBARA
MUSMAR
KHOR BARAKA
SUDAN
KARORA
MERSA TACLAI
DERUDEB
To KASSALA
ERITREA

Fig. 1. The Sudanese Coast of the Red Sea.

this strip consists of hard, coarse sand and gravel with stones in patches and hillocks. The commonest trees and bushes, which may grow as dense as an orchard, are *Acacia tortilis* and *Lycium persicum.* Undershrubs are *Indigofera paucifolia*, Del., *Salsola* sp. and *Cadaba* sp., which grow at intervals of 1 to 8 yards. The annuals mentioned below in the *Suaeda* belt can mostly be found near the hills, where they are, however, scattered and poor in quantity, *Zygophyllum simplex*, Linn., being the commonest (Plate I, fig. 2).

In places among the foothills there are large dunes, more or less fixed, which resemble the Kordofan *gozes* (see below, p. 71), except that the sand is yellow instead of red. These are covered with *Panicum* tussocks.

In the central strip of the coastal plain there are no trees or bushes other than an occasional *Acacia* or *Capparis decidua*, Pax. The soil consists of hard, coarse sand with fine gravel, on the surface of which springs a dense growth of *Aristida mutabilis*, Trin. & Ropr., while *Indigofera paucifolia*, *Salsola* sp., *Dactyloctenium scindicum*, Boiss., and *Dicoma tomentosa*, Cass., occur irregularly at intervals of 5–20 yards. This hard plain is, however, much overlaid with soft sand, which sometimes forms small hillocks round a tussock of grass, sometimes larger dunes. These dunes are more fixed in the southern parts where the rainfall is heavier, and looser in the north. Where this soft sand occurs, the undershrubs are largely replaced by *Panicum* and *Lasiurus* growing at 1–10 yard intervals, but the latter does not occur on the dunes. The commonest annual grass on the soft sand is *Brachiaria* sp., and *Heliotropium undulatum*, Vahl., is also common.

The above plants are the most characteristic and conspicuous in this area, but the following are abundant in patches on the soil between the dunes and are important food-plants of stock : *Crotalaria microphylla*, Vahl., *Indigofera hochstetteri*, Bak., *I. viscosa*, Lam., and *I. linifolia*, Retz.

East of the central plain and stretching to within about a mile of the sea is a belt of hard sand-dunes, which is characterised by an abundance of the fleshy-leaved bush *Suaeda fructicosa*, Forsk. (Plate II, fig. 2). The bushes, which are 2–7 feet high, grow at intervals of 5–20 yards. The soil of these dunes bears, in patches, a dense growth of *Chloris virgata*, Swartz, which annual grass may grow as densely as 300 plants to the square foot. Mixed with it to the extent of 1–20 plants per square yard is the procumbent annual grass *Cenchrus setigerus*, Vahl. and *C. pennisetiformis*, Hochst. & Steud. On the harder flat ground between the dunes, *Aristida funiculata*, Trin. & Rupr., grows in dense patches. Scattered among the patches of grass, and also in open spaces the following are common :—*Eragrostris ciliaris*, R. Br., var. *brachystachya*, Boiss., *Indigofera hochstetteri*, *I. viscosa*, *Euphorbia* sp. (small annual), *Zygophyllum simplex. Neurada procumbens*, Linn., *Crotalaria microphylla*, *Lannaea glomerata*, Cass., *L. nudicaulis*, Hook.

On softer sand, as around small, dry water-channels, *Brachiaria* sp., *Eleusine flagellifera*, Nees., *Heliotropium undulatum*, *Merremia pedata*, Hall., *Commelina forskalei*, Vahl., and *Tribulus terrestris*, L., are common.

Tussock grasses and undershrubs are not much in evidence in the *Suaeda* belt. The annual grasses appear two days after the first heavy rain, but their later development is slower than is usual in the tropics, owing doubtless to the cool season in which the rains come. The dicotyledonous annuals develop slower than the grasses, but remain green for a longer period.

The above is not by any means a complete list of plants occurring in this area, but merely indicates the commoner and most characteristic members of the associations.

These *Suaeda* dunes are harder in the south where there is more rainfall and annual vegetation, while in the north they are often covered with loose blown sand. In the area near Tokar the coastal plain becomes much wider, and there are very strong winds during most of the year. As a result of this, blown sand is much more in evidence than might be expected from the rainfall.

The strip of the coastal plain immediately adjoining the sea has a peculiar vegetation as the ground is salty. There are flat salt-pans bearing no vegetation, interspersed with larger or smaller stretches with a fairly dense growth of *Aleuropus lagopoides*, Druce, and *Sporobulus spicatus*, Kunth., and the undershrubs *Zygophyllum coccineum*, L., a small *Suaeda* and *Arthrocnemum perenne*, Miller. There are mangroves at the edge of the sea in some places.

The above description of the coastal plain is only approximately true, as in many cases the stony belt may send eastward arms nearly to the sea, while in some places the *Suaeda* belt is interrupted for many miles, being replaced by soft sand and tussock grasses.

The khors, when they leave the foothills may soon split into a series of smaller channels and lose themselves in the sand before they reach the sea. Most of the larger khors, however, continue across the plain in one or two definite channels until they reach the *Suaeda* belt, where they may spread out, forming deltas. A few khors, such as Arbaat and Baraka, rise in the western hills, and have a long course before they reach the plain. These flood during the *kharif* rains (July–August) and Khor Arbaat may flood again during the winter rains (November–March). These khors, especially the Baraka, bring down a great deal of silt and clay when they flood, and most of this is deposited in the deltas near the sea. The majority of khors, however, rise in the eastern hills, and, having a short course, bear little silt or clay. Heavy local rains on the plain may produce temporary khors, or floods without any definite channel.

Climate of the Red Sea Coast (fig. 2).

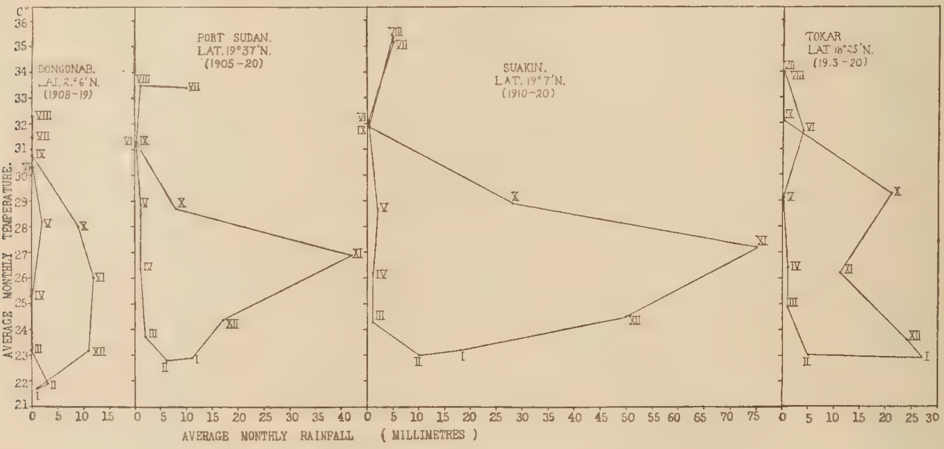


Fig. 2. Climate of the Red Sea Coast.

Rainfall.

The Red Sea coast differs from the inland parts of the northern Sudan in the period of its rainy season, which occurs in the winter (November–January) instead of in the late summer (July–September), the latter being the normal rainy season inland.

These winter rains fall on the coastal plain and on the eastern side of the range of hills ; west of this line rain does not usually fall in the winter (fig. 1).

The coastal winter rainfall is greater than the summer rainfall of places at the same latitude on the Nile, the isohyets after crossing the hills taking a south-westerly direction on the map. Although the winter rain is scanty, it has more effect on the vegetation than would the same amount of summer rain inland. The reason is that it falls during the cool season of the year and that near the coast the air is more humid than in the inland parts, both of which factors reduce evaporation.

TABLE I.

*Normal Monthly Rainfall for Red Sea Stations.**

Month	Dongonab	Port Sudan	Suakin	Tokar	Aqiq
January	1	11	18	27	53
February	3	6	10	5	20
March	0	2	1	1	7
April	0	1	1	1	1
May	2	1	2	0	3
June	0	0	0	4	1
July	0	10	5	0	1
August	0	1	5	0	2
September	0	0	0	0	1
October	9	8	28	21	1
November	12	42	75	11	21
December	11	17	50	24	27
Total	38	99	195	94	138

* All temperatures mentioned are Centigrade and rainfall is in millimetres.

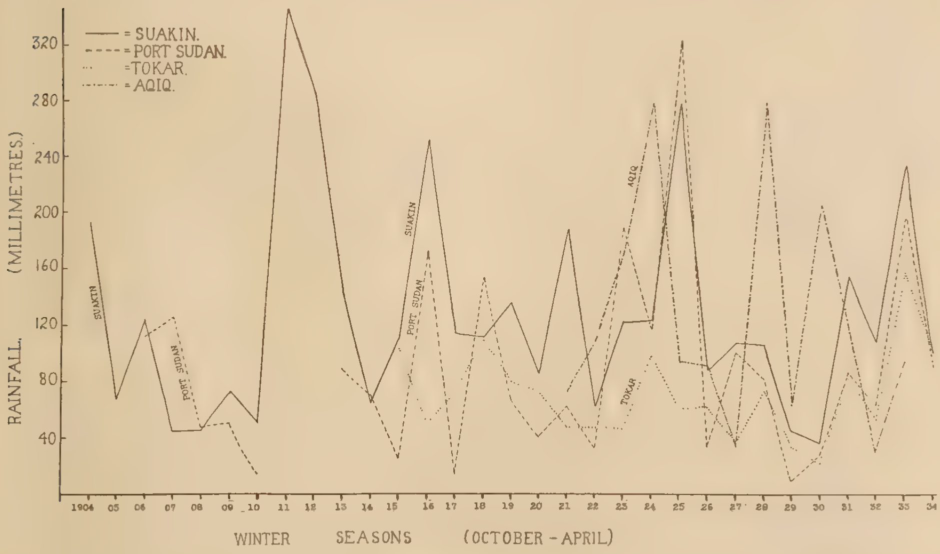


Fig. 3. Chart of winter rainfall (October–April) at Red Sea Coast Stations (1904–1935).

North of Port Sudan the rainfall is less than in the southern parts. November and December are usually the rainiest months, but rain may also be expected in January and February, when it usually falls in the form of drizzle. If this drizzle falls continuously for several hours it has some effect on the soil and vegetation ; but if it falls spasmodically, with bright intervals, it usually dries up without penetrating the soil.

South of Tokar, the rains occur often later, January being the wettest month at Aqiq.

The above remarks are general, but the rain on the Red Sea coast is very capricious, especially north of Port Sudan where it is very rare for the whole coast to receive effective rain in one season, while some areas may experience two or more rainless years. The rain is often very local ; heavy rain may fall in an area of perhaps a square mile, while the surrounding land receives only some drops. In a good year the first heavy rain may fall in October, and there may be effective rain every month up to and including February. Fig. 3 illustrates the variations of the winter rains during a series of years.

Summer rains fall on the hills, and occasionally an odd shower may reach the coast. Vegetation springing up after such a shower usually dies quickly, in the absence of further rain.

Temperature (fig. 2).

Owing to the influence of the sea, air temperatures on the coastal plain are less extreme than inland. The northern parts are cooler than the southern. January and February are the coolest months, while July and August are the hottest. The normal maximum and minimum screen temperatures at Port Sudan are 40·4° and 28·2° in August, and 27·2° and 19·1° in February. The daily range of temperature is 12·2° in the summer and 8·1° in the winter. At Dongola, which is at about the same latitude, on the Nile, the daily range of temperature is about 19° in the summer and 18° in the winter.

Wind.

There is usually a wind blowing on the Red Sea coast, though violent storms are not usual. North of Suakin, the prevailing winds are northerly throughout the year, but strong south winds blow spasmodically in the winter to the north of Dongonab. This south wind is said to bring rain. In cold weather the wind is usually from the north.

South of Suakin, and especially near Tokar, the winds are much stronger, and dust storms are common. The strong south wind begins usually in June, and continues until the end of September, when the wind veers round to east and north-east, and is then not quite so strong, but still produces dust storms. During the cool weather, usually in January and February, the wind is from the north and the air is clear of dust. This lasts, with odd stormy periods, till the south wind sets in again.

Humidity.

The records available are from stationary wet and dry bulb thermometers, and only one reading a day is available for some stations, so the normals are not comparable.

The atmospheric humidity of the coastal plain is much higher than that of inland areas, owing to the proximity of the sea. The driest months are June, July and August. At Port Sudan, where three readings a day are taken, the normal relative humidity is 46–48 per cent. during these months, and 65–72 per cent. from October to April.

Occurrence of solitary Schistocerca on the Red Sea Coast in the Winter 1933–34.

Swarms of *Schistocerca* were apparently present on the Red Sea coast during the winter from 1925–26, when the initial formation of phase *congregans* was observed by Johnston, until 1931–32, when the immigrant swarms were small and the resultant hopper bands scattered by birds. During the winters 1932–33, 33–34, 34–35, there were no immigrant swarms.

Observations on the occurrence of solitary locusts were made during the winter 1933–34. There was therefore no danger of confusion with individuals from swarms.

The Sudanese Red Sea coast may be roughly divided into two parts to the north and south of latitude 20°N.

The northern half.

In the northern parts which receive less rain there is practically no cultivation. In most years rain does not fall over the whole area, so that a patchy condition of the vegetation is characteristic. The state of the *Panicum* tussocks is a fair guide to past rainfall. If rain has fallen during the season, this grass will be more or less green. If rain has not fallen for a year, the stems will be a yellowish brown, while if the area has experienced two years without rain the tussocks turn dark grey, and the rhizomes in many cases appear to die. In December 1933 the country round Halaib had received some rain. From there southwards, it was dry, except for two small patches.

When travelling by camel any locusts on the route were observed, and in camp searches were made by two men or more. In Khor Shellal near Halaib, two solitary *Schistocerca* adults were found in the wide khor bed near the foothills. Two adults were also found in a khor just south of Shellal. Among the foothills of Jebel Elba there are large dunes covered with *Panicum* tussocks. These were searched thoroughly, but no locusts were found. Many unsuccessful searches were made on the plain near Halaib, where there are stony ridges with blown sand and *Panicum* in the hollows. The above places had all received rain and the vegetation was green.

South of 22°N. no more locusts were found until Shinab, where two adult *Schistocerca* were taken in the khor bed. One more locust was found in this northern area at Ballolab. In both these places the vegetation was green. In March one solitary *Schistocerca* adult was found at Khor Handakteb south of Mohammed Gul, which area had experienced two rainless years, and the vegetation was all withered. When the country west of the winter rain area was visited in March near Gebeit, no locusts were found, but the country was dry, and the atmospheric humidity low.

On the coast it was not till the country south of latitude 20°N. was reached that one could be fairly sure of finding a locust during half an hour's search. The only definite record of *gregaria* swarms breeding north of 21°N. was in January 1931. The few solitary adults found in December 1933 might therefore be expected to resemble phase *solitaria*. It is surprising to find them apparently resembling phase *gregaria* more closely than those taken in the south (see measurements, p. 54). The numbers available are, however, too small to make any positive deduction from the measurements.

From the above observations it will be seen that solitary *Schistocerca* were scarce north of latitude 20°N. All the individuals except one were found in areas that had received rain.

The southern half.

South of latitude 20°N., rainfall is heavier, and it is not unusual for rain to fall over most of the coast in one season in sufficient quantity to produce good grazing. Although by far the larger part of the land is untilled, cultivation takes place to a small extent. This is confined to the *Suaeda* belt of the coast, except in the case of the Khor Baraka. On this delta, cotton is grown on the flood which comes down in July and August, and *dukhn* (bulrush millet, *Pennisetum typhoideum*, Rich.) is grown for some way up the khor bed.

Apart from the Khor Baraka delta, cultivation takes place in the winter, and is confined to *dukhn* and water-melons. In khors which have small deltas, the crop may be sown after a flood, and if there is fairly heavy rain, other land may be sown, usually adjoining a khor. Towards Tokar, where the coastal plain widens out, cultivation is more widespread, and usually takes place in the neighbourhood of loose dunes, as *dukhn* grows best on very sandy soils. The method of cultivation is similar to that practised over most of the northern Sudan. The land is kept clear of most trees, bushes and undershrubs, and is weeded of annuals two or three times during the season.

In the tree belt of the plain, solitary locusts are mainly confined to the sandy khor beds where 1–3 could be found in 20 minutes. In the central belt, *Schistocerca* were scarce on the hard gravelly soil, but commoner on the softer sand, especially on the *Panicum* dunes, where 2–6 could be found in 20 minutes. In the *Suaeda* belt, odd solitary individuals might be met with on the dunes, but the large majority were confined to the neighbourhood of *dukhn* cultivation, and it is here that the outbreak centres were found.

Description of Outbreak Centres.

The following refers to the breeding season November 1933–April 1934.

Khor Arbaat.

This khor which rises near Sinkat, divides into three branches on leaving the foothills and forms three small deltas, which are cultivated. The most southerly khor, Egaiet, is considered here.

Egaiet delta is about one mile broad at its widest part, and the surface soil is mostly silt and clay. The actual khor bed, shallow but still evident in the delta, is sandy. Outside the delta are *Suaeda* dunes with some patches of stony ground. The surface of these dunes is fairly loose. In January 1934 the annual vegetation on these dunes was very luscious. The locusts present were a few old mature adults, green hoppers of all stages and a few young adults. The hoppers were mostly found on the greenest patches of annuals, where about eight could be found to the square yard. The mature adults were almost certainly the parents of the hoppers, which represented the first winter generation. The earliest effective rain here was at the end of October, and the first eggs would have been laid in November. Some of these original females must have laid more than one batch of eggs, as the hoppers were of all ages, and the few old females still alive had large eggs in their ovaries. Some were found dead with full ovaries.

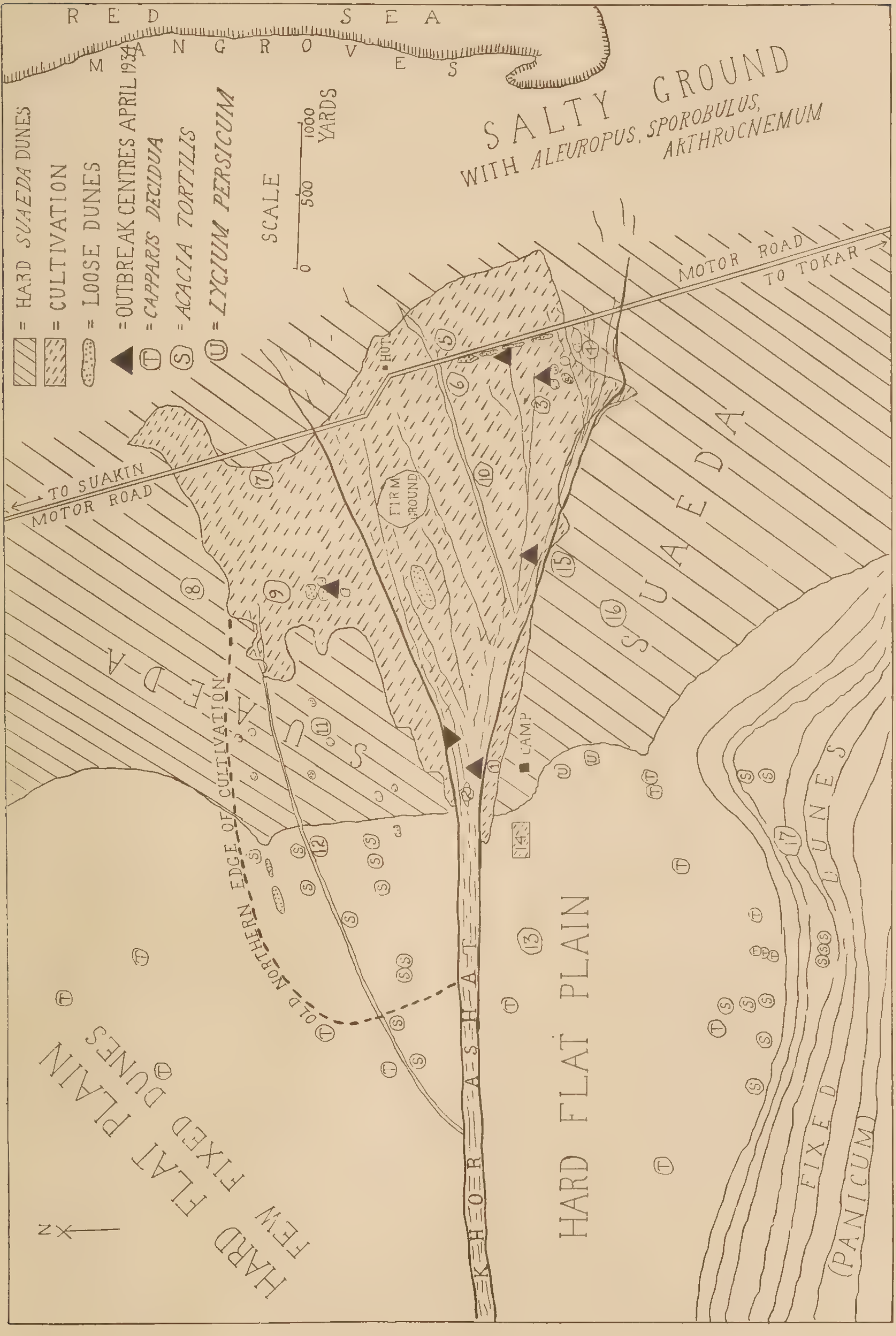
Egaiet was next visited on 21st February. No effective rain had fallen since December, and the vegetation was dry. The *dukhn* crop was mostly dry except in the actual khor-bed where it was still green. The majority of the January hoppers were adult, and were concentrated among the green *dukhn* in the khor-bed. There were a few old hoppers still outside the cultivation. Many of the adults were sexually mature, and a few young hoppers were found in the khor-bed, where the sand was moist within 1–3 inches of the surface. Elsewhere moist sand could not be discovered nearer than 6 inches from the surface.

Arbaat was not visited again by the writer, but an assistant went there in April. He found very few green hoppers, and a reduction in the number of adults.

In the season under consideration swarming did not take place at Khor Arbaat, but it was here that Johnston (1926) observed the initial swarming of *Schistocerca* in 1926.

Khor Ashat (fig. 4).

This khor is further south, half-way between Suakin and Tokar. It rises in the eastern hills, and has but a short course to the sea. It normally floods in the winter though small August flushes may occur.


RED SEA
MANGROVES
= HARD *SUAEDA* DUNES
= CULTIVATION
= LOOSE DUNES
▲ = OUTBREAK CENTRES APRIL 1934
Ⓣ = *CAPPARIS DECIDUA*
Ⓢ = *ACACIA TORTILIS*
Ⓤ = *LYCIUM PERSICUM*
SCALE
0 500 1000 YARDS
SALTY GROUND
WITH *ALEUROPUS, SPOROBULUS, ARTHROCNEMUM*
MOTOR ROAD
TO TOKAR
TO SUAKIN
MOTOR ROAD
HUT
FIRM GROUND
SUAEDA
SUAEDA
CAMP
OLD NORTHERN EDGE OF CULTIVATION
KHOR ASHAT
HARD FLAT PLAIN
FIXED DUNES
(PANICUM)
HARD FLAT PLAIN
FEW FIXED DUNES
N
1
2
3
4
5
6
7
8
9
10
11
12
13
14
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16
17

Fig. 4. The Mouth of Khor Ashat.

The khor spreads out on entering the *Suaeda* belt into a delta of over one mile in width. Owing to the short course of the khor, very little clay or silt is deposited, so that the delta is more sandy than that of Arbaat. The delta is cultivated, but most of the cultivation is outside it, to the north. As a consequence of cultivation the original hard *Suaeda* dunes adjoining the khor to the north have had their surface loosened and the vegetation altered. North of the khor and west of the present cultivation there is an area of about one square mile which used to be tilled. Here the vegetation (Plate II, fig. 1) consists mostly of *Heliotropium undulatum, Commelina forskali* and *Brachiaria* sp., and the sand is light in colour and very loose. Beyond the zone of old cultivation are the typical *Suaeda* and *Panicum* belts (see p. 39).

Ashat was first visited in February 1934, when the vegetation was all fresh and green. *Schistocerca* adults and green hoppers were to be met with everywhere and there were more young adults than at Arbaat. It appeared at the time that the majority were outside the cultivation, but further work, carried out at Ashat in the following winter, makes it seem likely that this was a wrong impression (see p. 51). A few of the young adults were mature at this time (17th February).

The next visit was on 6th March. The annuals outside the cultivation were mostly dry, but the *dukhn* and any weeds among it were still green. *Schistocerca* adults were abundant among the cultivation, and scarce outside it. All those examined were sexually mature, and some females were observed ovipositing. Green hoppers were fairly common among the cultivation.

On 28th March, a stay of three weeks was begun at Ashat. It must be realized that, owing to females laying more than one lot of eggs, and at different times, the generations became overlapping and impossible to separate. In the only cage experiment made, newly moulted adults were collected at Tokar on 11th March and taken to Ashat. These were *in copula* on 2nd April, and the first egg-packet was laid on the 8th April. These females were all dead at the beginning of May. This experiment would indicate about one month from final moult to oviposition. These locusts had experienced a little drizzle on several days from 12th to 21st March.

At the end of March, *Schistocerca* adults were not very numerous at Ashat, but hoppers were abundant. Young hoppers were common throughout the delta, but were in large numbers only on the mats of *Heliotropium undulatum*. This is a deep-rooted plant which grows on the soft sand, and if the ground is not weeded properly, it forms large mats, each covering a square yard or more. It is most abundant among the cultivation outside the khor-bed, especially where the crop is thin and the owner does not trouble to weed it (Plate I, fig. 1).

These hoppers were mostly of the first and second instar at the end of March. All those of the first instar were green, and most of the second instar were green with the black *gregaria* markings more or less developed. The dark pattern may appear at any instar except the first. The first marks to appear are those on the hind femora, the posterior half of the dorsal surface of the pronotum, and the dorsal surface of the abdomen. Later the marks at the sides of the abdomen and on the front and sides of the pronotum and head appear, and the antennae darken in colour. It may take one or more moults before the green background is replaced by fawn or yellow. Sometimes the complete dark pattern may be developed, and the green colour lost after the first moult. It was found that a green *Schistocerca* hopper of the first instar acquired the swarming colour when caged with hoppers of other species.

After control measures had thinned out the numbers, young, coloured hoppers usually reverted to the green colour, whereas the older ones retained the yellow or fawn colour with some reduction of the black pattern. As there is plenty of evidence as to the complete absence of swarms in the year under consideration, it may be concluded that these were hoppers of the phase *congregans*.

The young *congregans* hoppers were very inactive. They remained mostly on the *Heliotropium* on which they fed. On a mat of this plant covering a square yard of ground there were perhaps 300 hoppers. When disturbed, they would jump about, a few reaching the ground but returning to the plants. A thermometer arranged with the bulb on a plant of *Heliotropium* read up to 37°C., but no marching was observed, nor did any hoppers descend to the ground to sun themselves. In other words they behaved, when undisturbed, as solitary hoppers.

When the hoppers became older (third and fourth instar) they were more active, and marched about the cultivation, feeding on the *dukhn* as well as on other plants. At this stage they had been much reduced in numbers by poisoning, but the majority had the swarm coloration.

The inactivity of the young *congregans* hoppers was probably due to their small size and the nature of their surroundings. For the majority were still inactive after they had acquired the *gregaria* markings, and it was not until they increased in size that general marching took place. The conditions of life in a tangled mass of *Heliotropium undulatum* about 4 inches high must be quite different from life in a cage with the same density of hoppers, where there is no dense mass of vegetation impeding movement. The branches of this plant are as thick as the bodies of the young hoppers and separate them one from another. In addition, a small hopper reacts to disturbance less than does a big one, so that there is less jumping to increase the disturbance ; and as they jump only a short distance, they do not reach the ground and the commotion dies down in the tangle of vegetation. In the case of a big hopper, the vegetation is comparatively smaller, and the insect reacts more strongly to stimuli. Hence a disturbance spreads more rapidly and dies down more slowly.

These remarks are borne out by the only occasion on which young *congregans* hoppers were observed marching. This was up the khor (see fig. 4) where there is a little *dukhn* on each bank. Here there are large plants of *Heliotropium* on the banks, but the khor bed is mostly bare sand. About 300 first and second instar hoppers were disturbed, and jumped off a plant on to the bare sand, whence they proceeded to march across the khor. On reaching the thick vegetation on the other side, they lost their impetus and stopped marching. On this occasion the temperature of the sand was 38° at the surface.

On 2nd April police from Tokar started poisoning operations. Meanwhile the older hoppers became adult. A number of these young adults were caged on 10th April, and dissected on 10th May, when they were found to be sexually immature, as were those in the field at this time. By the end of April, the cultivation at Ashat was nearly all withered, and animals were let into it to graze. The *Schistocerca* adults were abundant but represented only a small fraction of the hopper population before control measures began. At Ashat, most hoppers had hatched before 4th April ; but small numbers continued to emerge until the end of April.

Before returning to Khartoum in the middle of May 1934, 60 young adults were caged and taken to Khartoum, where they were provided with green food and a glass of moist sand. The second half of May is in the *rashash* season in Khartoum. The south wind was blowing spasmodically in dust storms with drops of rain. The relative humidity was 20–30 per cent. By the end of May the relative humidity was 25–45 per cent. One egg-pod was laid on 6th June. On 21st June there was 20 mm. rainfall, which was early for this latitude. The humidity rose to 85 per cent. for part of the day, and 3 pairs of locusts copulated in the afternoon. There were at this time 21 females and 27 males surviving. The morning following the rain two egg-pods were laid, after which egg-packets were laid on most days, totalling seventy-one up to the 12th August 1934. There were then only 5 females and 8 males surviving. The first egg-pod hatched on 25th June. All the hoppers were greenish at first, but about half were of the swarm colour within three hours.

The fact that some locusts copulated immediately, when a high humidity was obtained, and laid eggs on the following day, suggests that some of them must have been sexually mature, but lacked the stimulus to copulate. The high fertility of these locusts (over three egg-pods per female) demonstrates the magnitude of the outbreak which might have occurred, if a swarm of these locusts had reached the summer-rain areas of the Sudan. It is interesting to compare the fertility of these locusts with that of what were presumably the same generation, when experiments were made in November 1934 (see p. 53).

Hamasheb and the Western Side of Khor Baraka Delta (fig. 5).

The Baraka flood does not flow constantly in the same channels, so that part of the delta is always dry. At present the flood has reached its south-eastern limit, whence it will, if not interfered with, gradually work back towards the north-west, until the present cotton area of south-east of Tokar is dry, and the khor flows north-west of the town. The dry western side of the delta has a clay floor with some silt. On this floor are dunes composed of sand mixed with clay and silt, which tend to become firm on the surface after a good rainy season, but are blown about subsequently by the strong winds of the summer, which also cut channels in the ground. On its extreme north-western edge, the delta terminates in a series of crescent-shaped, wind-blown sand-dunes which do not bear any vegetation.

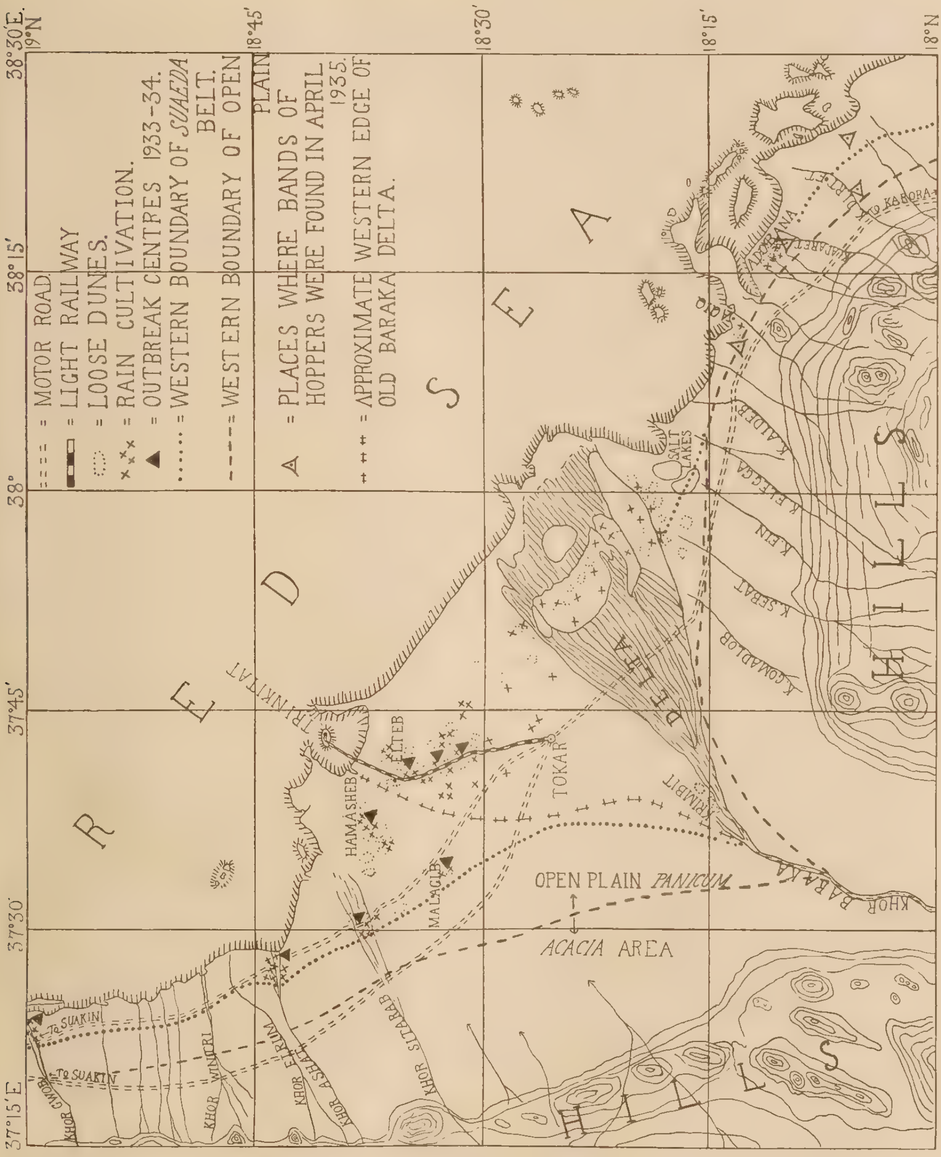
In the middle of these is Hamasheb. When heavy rains fall, a local flood comes down from about 10 miles to the south-west without any marked channel. This water is stopped and soaked up by the dunes, and *dukhn* is grown on the ground between them. Hamasheb is bounded on the north-west by a large salt flat. The sand when once thoroughly wet dries very slowly, and the *dukhn*, sown in November, was still green at the beginning of May although no effective rain had fallen since February. As a result of the wind blowing the dry loose surface sand about, the moist sand below becomes exposed in places, so that ideal oviposition sites were available until May.

Hamasheb was first visited on 20th April. The large majority of locusts were in and near the cultivation. The young hoppers were still hatching in large numbers, and were more numerous than at Ashat. They were nearly all on the plants of *Heliotropium*, which occurred, as at Ashat, among and at the edges of the cultivation. At this time there were also bands of older marching hoppers, which sometimes left the cultivated area and marched over the dunes. On 21st April there were still a fair number of mature adults present, and abundant newly-moulted locusts. Hatchings continued in small numbers until 4th May. Control measures were begun on 22nd April. By 4th May the remainder were mostly adult and abundant, but did not migrate. They were not sufficiently numerous to form a small swarm. A letter was received from the Sheikh of Hamasheb saying that on 6th June the strong south wind had come, and that the locusts had moved and fallen into the sea.

South-east of Hamasheb rain cultivation is carried out on the unflooded delta. The *dukhn* is sown in patches, usually round the mixed sand and clay dunes. The clay floor is covered with *Suaeda fructicosa* bush and bears many of the weeds which grow among the cotton (see p. 39). On 26th April *congregans* hoppers could be found in and among most of the patches of *dukhn*. The hoppers were mostly of the fifth instar and there were many pink adults. Several bands had marched away from the *dukhn*, and were spending the night on *Suaeda* bushes, 10–50 on each bush. Control measures were instituted on about 25th April—too late to have much effect.

On 2nd May there was a good deal of voluntary flying and circling round. On about 8th May these locusts migrated as a swarm, slowly in a westerly direction. They were last seen west of the upper road, covering an area of about ¼ mile square, flying near the ground towards the hills. They were not subsequently heard of and doubtless scattered.

It will be noticed that there were no young hoppers in this area on 26th April, although they were numerous at Hamasheb at this time. This was probably due to the fact that the silt, sand and clay dunes of the western delta dry up more rapidly



= MOTOR ROAD.
= LIGHT RAILWAY
= LOOSE DUNES.
= RAIN CULTIVATION.
= OUTBREAK CENTRES 1933-34.
= WESTERN BOUNDARY OF SUAEDA BELT.
= WESTERN BOUNDARY OF OPEN PLAIN
= PLACES WHERE BANDS OF HOPPERS WERE FOUND IN APRIL 1935.
= APPROXIMATE WESTERN EDGE OF OLD BARAKA DELTA.
38°30'E.
19°N
18°45'
18°30'
18°15'
18°N
38°15'
38°
37°45'
37°30'
37°15'E
R
E
D
S
E
A
HILLS
HILLS
SALT LAKES
TRINKITAT
TOKAR
HAMASHEB
ELTEB
MALAGIB
TRIMBIT
OPEN PLAIN PANICUM
ACACIA AREA
KHOR BARAKA
K. SEBAT
K. GOMADLOB
KEN
KELEGGA
LADEB
AGGETEI
KARORA
To SUAKIN
To SUAKIN
KHOR GWOB
KHOR WINTRI
KHOR ERUM
KHOR ASHAT
KHOR ASHAT
KHOR SITAKAB

Fig. 5. Environs of Tokar.

than the pure sand of Hamasheb; and, in addition, as the surface is firmer, only strong winds will expose the moist layers beneath, so that the oviposition sites had disappeared in this area, while they still persisted at Hamasheb.

In addition to the above places, *congregans* hoppers were present at Khor Gwob, Khor Sitarab, and a patch of cultivation south of Sitarab, named Malagib. The numbers of hoppers in these places were small.

The Flooded Area of the Delta and the upper Reaches of Khor Baraka.

In the area flooded by the Khor Baraka the upper foot of soil consists mainly of clay and silt. Where the khor is still in a definite channel and at the beginning of its delta, the soil is more sandy. On the clay and silt areas, the following plants are common among the cotton :—*Panicum repens*, Linn., *Rhyncosia elegans*, *Grangea* sp., *Trianthema* sp., *Mollugo hirta*, Clarke, *Aristolochia bracteata*, Retz., *Gynandropsis gynandra*, L.

There are patches of high ground which the flood water does not reach, and deep khors found in places that carry off water which would otherwise irrigate the surrounding land, leaving dry areas of flat clay. In the high ground, the surface soil usually consists of loose brown silt, which forms dunes. Caged *Schistocerca* adults oviposited readily in this soil when moist, but it dries up more quickly than sand.

In the winter of 1933–34 when the rains were good, *dukhn* was grown on most unflooded parts of the delta, especially in khors and on the loose silt. On flat unflooded areas some parts were uncultivated, and a dense growth of annuals came up. In January, when this vegetation was green, *Schistocerca* adults and hoppers could be found in small numbers everywhere, except among the cotton, but were commonest on the looser soil among the *dukhn*.

In March, when most of the vegetation outside the cotton areas was withered, adults were still common among the *dukhn* on the dunes, and in Khor Abu Rish which is sandy. In large open spaces where there was no *dukhn*, or where the latter was dry, the young adults of early February were mostly found in small local khors where some vegetation was still green. But the moist soil in these small khors was at a greater depth, and no hoppers were found in March. In this month, odd hoppers were found in the silt dune areas, and there were small numbers among cultivation near the eastern sand-dunes, and in Khor Abu Rish. At the end of April a very few fourth and fifth instar hoppers were found in the two latter places. In none of these localities were the hoppers numerous, and all were green.

As mentioned above, the beginning of the delta is more sandy, but being further west normally receives little winter rain. Cultivation is therefore confined to the flood area. At Krimbit, hoppers could still be found in the middle of March, in rather larger numbers than in Khor Abu Rish.

South-west of Krimbit, the Khor Baraka flows in one channel, 100–200 yards in width, and there are tamarisk woods on the banks. The winter rain area is soon passed, but *dukhn* is still grown in the khor bed, which is moist from the July–August floods. There are strong winds all the year round in these regions, southerly from June to September, and northerly during the other months. Among the cultivation a very few *Schistocerca* adults were present in February 1934, and one fourth instar hopper was found. Moist sand was near the surface owing to wind action on the dry sand. Breeding of ph. *gregaria* was observed here by the writer in December 1930, and had also occurred in previous years.

Adobana.

This place is south-east of Aqiq near the sea. There is a large khor and sand-dunes with *dukhn* cultivation. This was green at the end of April and *Schistocerca* adults and hoppers were fairly numerous, but not sufficiently so to produce phase *congregans*. But there was no heavy rain in this area until the end of December, so that the initial breeding was doubtless delayed. There are some similar localities between Adobana and Karora.

Some Notes on Locusta.

Solitary *Locusta migratoria*, L., were found everywhere south of latitude 20°N. in similar situations to *Schistocerca*, and they were numerous among the cotton on Tokar delta.

They were very numerous at Khors Ashat and Hamasheb, and the orange and black colour was produced in the hoppers. At Ashat the majority were adult at the beginning of April, but were not nearly numerous enough to form a swarm. They were still sexually immature in the middle of May.

At Hamasheb, towards the end of April, there were bands of old marching hoppers, young hoppers emerging, mature adults and young adults. They were about as numerous as *Schistocerca*. At least three-quarters of these *Locusta* succumbed to poisoned bait. The resulting adults were intermediate between *gregaria* and *solitaria* in general appearance.

There are no records of swarms of *Locusta* ever having been present on the Sudanese Red Sea coast, though they apparently occurred on the Eritrean coast in 1932. *Congregans* hoppers were observed by the writer in small numbers on Tokar delta in December 1930, and in large numbers at Khor Arbaat in December 1931 and January 1932. On this occasion the hoppers marched away from the cultivation, and resulted in a small swarm of adults of *gregaria* appearance. For some reason these adults never flew during the day except when disturbed, when they would take off but settle again immediately. They continued to march like hoppers. They used to fly about voluntarily at dusk, but they never migrated, and were scattered by birds. It is curious that, although *Locusta* produces phase *congregans* quite frequently on the Red Sea coast, flying swarms have apparently never resulted.

Work at Khor Ashat in the Winter of 1934–35.

During the winter of 1933–34, the solitary *Schistocerca* adults which had spent the preceding summer in an immature condition, matured, presumably after the first rains at the end of October 1933. Eggs were first laid in November, and the resulting hoppers became adult from the middle of January 1934 onwards. These young adults became sexually mature and oviposited in March, and their offspring, emerging from the eggs towards the end of March, were sufficiently numerous and crowded for the transformation to the phase *congregans* to take place.

This result seemed to depend on three factors :—

1. Sufficient eggs being laid by the original old adults ; a high rate of hatching of eggs and survival of hoppers to ensure a large number of young adults.

2. Maturation of these young adults during the same season,* and plentiful oviposition.

3. Crowding of the second generation hoppers. This demands that the egg-pods must be laid fairly close together, and therefore that the young adults must be fairly crowded when they are mature. We have seen that the population of the young first generation adults was high only in certain restricted localities, and not over the whole coastal plain. If they were to scatter from any cause over wider areas before oviposition, the resultant hoppers would not be sufficiently crowded for the change to phase *congregans* to take place.

It was intended to investigate some of these points at Khor Ashat in the winter of 1934–35. This station was selected, as it had been an outbreak centre during the previous year, and because the areas nearer Tokar are too dusty during the early winter to make the use of recording instruments feasible.

The author arrived at Khor Ashat on 2nd November 1934, and from 7th November readings were taken as follows :—Maximum and minimum thermometers in

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* " Season " refers throughout to the winter rainy season, October to April.

Stephenson screen ; grass minimum ; maximum soil temperature from a maximum thermometer with the bulb just covered by the soil ; rain gauge ; wind directions from a wind vane were usually taken at dawn (5.30–6·00), noon and sunset (17·00–17·30). Some wind force readings were taken with an anemometer but this instrument broke down later.

A recording thermo-hydrograph was set up in the field 7 inches from the ground, shaded from the sun by a narrow thatch, 3 feet from the ground, and within a low fence of coarse meshed wire netting to keep animals off it. This instrument was checked and corrected regularly by comparison with a whirling wet and dry bulb hygrometer. The temperature 4 inches below the soil surface was taken with a recording distance thermograph for a period. Some of these meteorological observations are represented graphically in fig. 6.

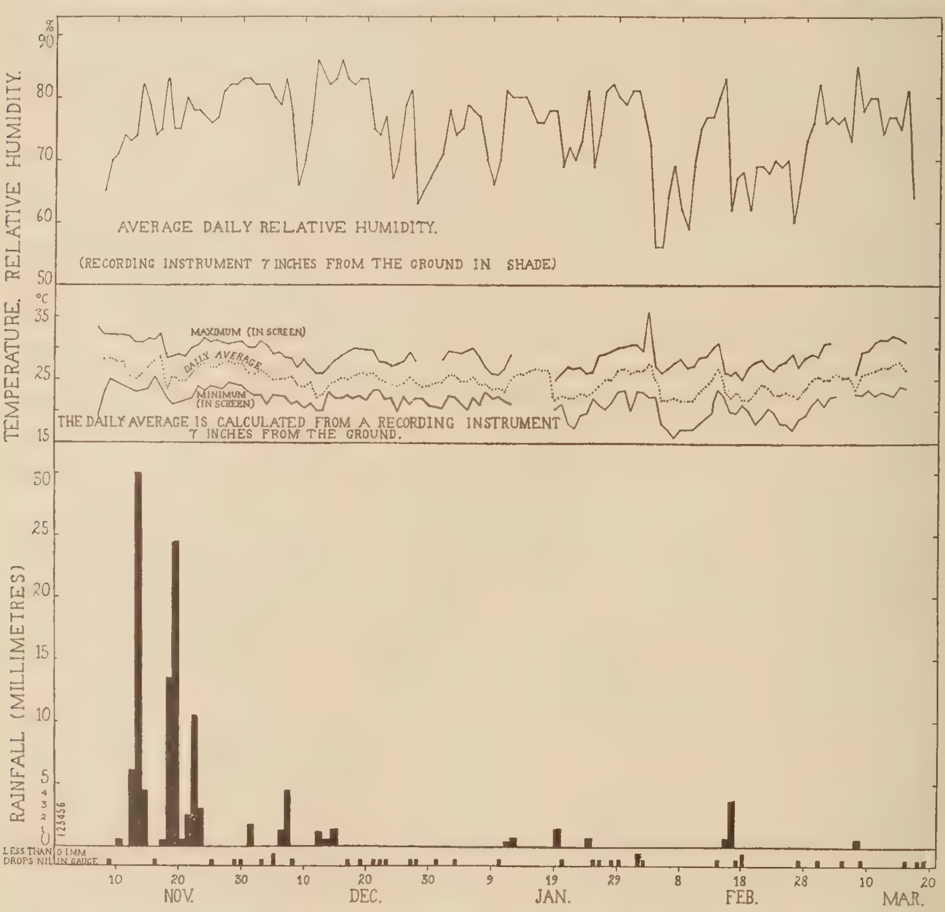

Fig. 6. Chart of weather at Khor Ashat, November 1934 to March 1935.

Maturation and Oviposition of original Adults.

During September a small flush of water had come down the khor and the *Panicum* and *Heliotropium undulatum* were green in the khor bed. Otherwise, the country was dry at the end of October.

The solitary *Schistocerca* adults were immature on 3rd November. Experiments similar to those carried out in Kordofan in 1933 by the author (1934) were planned to determine roughly the effects of high humidity on sexual maturation. Glass-sided cages with a cloth sleeve were used for the higher humidity, which could be roughly measured, but not controlled, and cages in the open for the lower. It was found that in practice the relative humidity inside the glass cage was 10–20 per cent. higher than that of the open air.

It was also intended to test the effect of artificially grown green food compared with the food obtainable in the field before the rains had come. Unfortunately the rains started on 10th November, and the adults in the field began to mature.

Before using locusts for experiments, they were kept for one day, to see that they had not been injured when captured. The cages used were 36 by 20 inches and 24 inches high. The sides and top were of galvanized wire of a coarser mesh than could be used for most insects. Four large glass tumblers were let into the floor, two being used for food-plants and two filled with damp sand for oviposition. There was a grass tussock in each cage reaching nearly to the top so that the locusts could sit in any position without having to use the wire sides which might be too hot.

In cage No. 1, 25 pairs were caged on 9th–14th November and kept in the open. The first pair copulated on 20th November after which they were all *in copula,* off and on, till they died. The original number of females was not added to, but any males dying were replaced. The first lot of eggs was laid on 4th December, up to which time 10 males and 4 females had died. Between 4th December and 11th January, 28 egg-pods were laid. By 11th January, all the remaining females were dead. The eggs of ten of these batches were counted and averaged 92, with 122 as a maximum, and 73 as a minimum. The rate of hatching was very high, only 1–6 per pod failing to hatch.

In cage No. 2, 37 pairs were caged at the same time as in cage No. 1 and kept under the same conditions. They started copulating on 20th November and continued as in cage No. 1. The first eggs were laid on 28th November, up to which time 3 males and 10 females had died. Between 28th November and 13th January, 32 egg-pods were laid. The last female died on 18th January. Twelve egg-pods averaged 81 eggs per pod, with a maximum of 112, and a minimum of 50. The percentage hatching was as high as in cage No. 1.

In both cages, males started acquiring a yellow colour on 24th November, and were all yellow by the end of November.

Ten pairs were caged at the same time in a glass cage, where the humidity was higher. They started to copulate on 16th November—earlier than those in the cages outside—but the first eggs were not laid until 30th November. These locusts died off rapidly, owing doubtless to the excessive humidity. The males started to become yellow on 20th November. All these locusts had spent the summer in a sexually immature condition. They were the survivors of the *congregans* of April 1934, after control measures had taken place. The hoppers which hatched from their eggs were in one case all green, but in the majority, a mixture of green and black hoppers.

In the field no adults were observed ovipositing. The first hoppers were found on 10th December, so that oviposition probably started in the field about 22nd November. The first young adults were observed in the field on 16th January and were numerous by 23rd January.

Measurements.

Table II gives the results of measurements of *Schistocerca* adults from the Red Sea coast. Series A and F from Kordofan are included for comparison. Only the ratio Elytra/Hind Femur is given.

TABLE II.

Measurements of Schistocerca *Adults.*

Series	No. measured		Value of E/F		
	♂♂	♀♀	♂♂	♀♀	Av. ♂♀
G	4	2	2.10	2·22	2·16
H_1	7	15	2·10	2·09	2·10
H_2	54	37	2·07	2·08	2·08
J_1	22	11	2·04	2·06	2·05
J_2	5	6	2·07	2·05	2·06
K	9	4	2·09	2·08	2·08
L	60	60	2·11	2·13	2·12
M	14	7	2·18	2·19	2·19
N	73	67	2·05	2·08	2·06
P	80	79	2·08	2·10	2·09
A	130	68	2·27	2·32	2·30
F	100	100	2·05	2·11	2·08

G=From north of latitude 20°N., December 1933–January 1934.
H_1=Mature adults from Arbaat, January 1934 (original egg-layers).
H_2= (F_1) Mature adults from Arbaat, February 1934 (offspring of H_1).
J_1=Mature adults from Baraka delta, February 1934 (original egg-layers).
J_2=(F_1) Young adults from Baraka delta, February 1934.
K=Mature adults from Ashat, February 1934.
L=(F_2) Young adults from Hamasheb, May 1934.
M=(F_2) Young adults from El Teb (the remains of the swarm which migrated), May 1934.
N=(F_2) Mature adults from Ashat, November 1934.
P=(F_3) Young adults from Ashat, February 1935.
A=Yellow swarm from Wad Medani, 1930.
F=" *Solitaria* " from Um Darag (Northern Kordofan), 1932.

It will be noticed that there is little difference in the ratio E/F in the case of H_1, H_2 from Khor Arbaat, or J_1, J_2, from the Baraka delta.

The F_2 locusts from El Teb (M) are nearer *gregaria* than those from Hamasheb, where the hopper bands had been reduced and scattered by poisoning.

Series N at Ashat had spent the summer of 1934 in an inactive condition ; they are probably of the same generation (F_2) as those of Hamasheb and El Teb. At Ashat control measures were carried out in April 1934. These locusts from Ashat are near *solitaria*, and their offspring (Series P) are slightly nearer *gregaria.*

Distribution of Solitary Schistocerca (fig. 4).

The delta of Khor Ashat is in places hard sand and clay, which is augmented by the small quantities of silt and clay brought down by the Khor. This is for the most part disturbed by cultivation processes, so that the surface is mostly soft sand, which in some places forms dunes. If a big flood comes down, most of the delta receives some water. This happened in the 1933–34 season, when there was heavy rain, and large areas were cultivated. In the 1934–35 season, only one small flood came down, and the rains were not prolonged. Consequently, a fair amount of land was left uncultivated, either hard ground which required more rain than loose sand, or ground very overgrown with weeds. Most of the cultivation is on land which does not normally get flooded. This may be seen from fig. 4, by noticing the cultivated area north and west of the actual flooded delta. In the land shown within the delta on the map there are many high places which never become flooded, and others which are only watered by an exceptionally big flood.

Before the khor-bed opens out into a delta, it consists of bare sand, with vegetation at its edges only, as the flood water runs too fast for any plants to remain rooted. There are a few islands which support a vegetation of *Leptadenia spartium*, *Panicum* and *Heliotropium*. This is undoubtedly the natural condition of the khor-bed. Where the khor spreads out and the flood water runs less swiftly, vegetation is plentiful in places where the land is not tilled. The vegetation of this delta, before it was cultivated, probably consisted of a dense thicket of *Suaeda*, *Leptadenia* and *Panicum*, with various annuals on the firm ground. The land outside the flooded area was of the ordinary hard *Suaeda* dune type with occasional small water-courses a few feet in width ; this is still the condition of the country south of the delta, where no cultivation has taken place.

North of the khor in the cultivated area, an unweeded patch produces a dense growth of *Heliotropium* on the loose sand, whereas the dominant annual on the hard *Suaeda* dunes is *Chloris virgata*, and on the hard parts of the flooded area *Cenchrus setigerus*. On the northern side of the khor, the cultivation used to extend farther west than at present. Its old western edge is shown on the map (fig. 4) by a broken line ; this area, which has been left uncultivated for some years, has not recovered its original vegetation. The sand is pale in colour and loose, whereas the surface of the firm *Suaeda* dunes is darker, probably owing to the presence of iron salts which have a cementing effect. Some *Suaeda* bushes have come up in this area of old cultivation, but the ground vegetation consists of *Heliotropium*, *Brachiaria*, and *Commellina forskali*, with much bare ground. This gives place to the hard plain on the west, and to the hard *Suaeda* dunes on the north.

The method finally adopted for counting adult locusts was to walk in a given area for 20 minutes at the rate of about 3 miles an hour, and count all the locusts seen. Counts were only made if the sun was out and the air temperature 27°–31° and the relative humidity above 55 per cent., as coolness, cloudiness or low humidity reduces the number of locusts seen. During November and the first half of December, these conditions were often not obtained for long during the day, so that figures for many places are not available. Counts of the old adults made after the end of November are not given, as by that time some were dying off.

During November the solitary *Schistocerca* adults were to be found in fair numbers all over the cultivated area. Counts gave 2–9, the highest numbers being among the northern cultivation outside the flood limit. Outside the cultivated area locusts were much less common. In the area of old cultivation north of the khor, counts gave 1–5. On islands, and banks of the khor, an odd locust might be found. On the hard plains west of the *Suaeda* dunes, counts gave 0–1, on the *Panicum* dunes 0–4, and on the *Suaeda* dunes none were found.

Counts of hoppers were made from 24th to 31st December. Small hoppers are difficult to see, and the method used was to walk very slowly, in a bent position, tapping every plant within reach with foot or stick. If any movement was noticed, the observer knelt, and investigated more closely. As slight movements had to be observed, a strong wind made the conditions unsuitable for this work. The numbers given below are the numbers caught by two men in a quarter of an hour in sunshine. The station numbers are shown on the Map (fig. 4) surrounded by circles.

Station No.		*Hoppers*
1.	Cultivation opposite camp, unweeded	27
1a.	,, ,, ,, weeded	8
2.	Island in khor ; no cultivation	14
3.	Cultivation with mounds of sand, unweeded	18
3a.	,, ,, ,, weeded	9
4.	Uncultivated patch, hardish ground	2
4a.	Sown but unweeded, ,, ,,	2
5.	Cultivation east of road, weeded, hardish ground	2
6.	,, west of road, unweeded, ,, ,,	4
7.	Cultivation outside flood, hard ground, unweeded	0
8.	*Suaeda* dunes with some soft sand, north of cultivation	5
9.	Cultivation on soft sand with mounds, unweeded	59
9a.	,, ,, ,, ,, ,, weeded	18
10.	Cultivation not flooded this season, hard sand loose on surface, weeded	14
10a.	As No. 10, but unweeded	20
11.	Old cultivation	9
12.	,, ,,	6
12a.	Small khor with much *Heliotropium*, near 12	33
13.	Hard open plain	1
14.	Isolated cultivation, in hard plain, weeded	1
15.	Hard *Suaeda* dunes south of cultivation	0
16.	,, ,, ,, ,, ,,	0
17.	*Panicum* dunes	3

From the above counts these facts emerge.

1. Most hoppers were on soft sand cultivation, the probable reason for this being that the females prefer such soil for oviposition, and also because *Heliotropium* occurs there. The question arises as to why hoppers and adults should not be equally numerous on the soft sand which has gone out of cultivation (Stations 11 and 12) and where *Heliotropium* is also abundant. The probable reason for this is that *Heliotropium* is an evergreen plant only under certain conditions. In the cultivation where there is much bare ground owing to weeding, the deep rooted *Heliotropium* remains more or less green throughout the year, whereas it dries up more rapidly under conditions such as obtain in Stations 11 and 12.

2. More hoppers were found on unweeded land than on weeded land (compare Stations 1 and 1a, 3 and 3a, 9 and 9a, 10 and 10a). The reason for this is probably the preference of the hoppers for *Heliotropium* as a food-plant. There were no large stretches of completely weeded land. Each cultivator would start to weed his own little patch, and the hoppers doubtless left their *Heliotropium* plant when it was uprooted and withered, and found their way to a new one. This was exemplified in one fairly large area which was well weeded except for a strip about a yard wide that was left unweeded to mark a boundary. The *Heliotropium* plants in this strip had a population of about 40 hoppers to a large plant covering about an 18-inch square of ground, whereas before the land was weeded only 2–8 hoppers could be found on the plants of *Heliotropium* which were scattered about the cultivation.

In other words, the hoppers tend to concentrate on plants of *Heliotropium* in preference to the *dukhn* or other plants. It will be recalled (see pages 46, 47) that in the 1933–34 season the young *congregans* hoppers were always found in large numbers on the *Heliotropium.* If this plant were absent, the hoppers would presumably be scattered (in the absence of an attractant) on the plants of *dukhn*, and greater numbers would be needed to produce the initial crowding necessary for the transformation to the phase *congregans.*

Distribution of Young Adults.

The majority of hoppers had become adult by the end of January 1935. Owing to the original females laying eggs at different times, and some laying more than one batch, hoppers were not all of the same age.

Counts of the young adults were made from 15th to 28th February in the same manner as for the old adults. In the cultivation, the harder ground gave 15–20; the soft sand with mounds 35–45, and where the *dukhn* was greenest, 55. *Dukhn* and *Heliotropium* remain green for longer on soft, loose sand than on harder ground.

West of the cultivation, counts along the khor banks gave 23–35; north of the khor, in the area of old cultivation, 17–20. South of the khor on the harder ground the figures were 0–3. In the isolated patch of cultivation west of the camp, 44 were found. On the *Panicum* dunes, the figures were 2–8, while none were found on the *Suaeda* dunes by counting, though an odd individual was to be met with occasionally. No counts were made east of the cultivation, as the ground here becomes salty, and locusts are not normally found on it.

Sexual Maturation of Young Solitary Adults.

On 17th February 1935, 120 young adults were dissected. Four females had small eggs in their ovaries, and the ovaries of 12 others had swollen, which is the prelude to development of eggs.

On 17th March, 60 females were dissected. Of these, 10 had well developed eggs and 12 appeared to be mature.

On 5th March a very few first instar hoppers were found at the edges of the khor and round certain dune areas, where the sand was then damp at about four inches from the surface.

Up to the time of departure (20th March) very few more hoppers had hatched.

It would appear, therefore, that only a few of the young adults became sexually mature in the field.

Cage Experiments on Young Adults.

By the middle of February, the *Heliotropium* outside the cultivation was half withered in most places, and wilting *dukhn* could be found in some places. In the following experiments "good food" means fresh *Heliotropium* and *dukhn*, and "poor food" is the same plants half-withered in the field.

Cage No. 1.

15th February—Females which became adult on 15th–30th January caged without males. Good food.
18th March—One yellow male and one brown male from Cage No. 2 added.
19th ,, Both males *in copula.*
17 females dissected, 5 with large eggs, 10 with medium eggs, 2 immature.

Cage No. 2.

15th February—Males which became adult 15th–30th January caged without females. Good food.
14th March—Most had turned yellow.

Cage No. 3.

24th December—Eggs hatched and resulting hoppers crowded in cage. Assume *gregaria* coloration.
6th–12th February—Became adult. Good food.
19th March—No signs of maturation. Taken to Khartoum.

Cage No. 4.

15th February—Males and females from the field, which became adult 15th–30th January, caged. Poor food.
12th March—1 pair *in copula*.
14th ,, 1 egg-pod laid.
18th ,, 1 pair *in copula*.
19th ,, 1 egg-pod laid.

15 females opened, 7 with large eggs, 5 with small eggs, 3 immature.

Cage No. 5.

End of February—Males and females from field, which became adult 15th–28th February, caged. Good food.
19th March—No signs of maturation. Taken to Khartoum.

Cage No. 6.

16th February—Males and females from the field, which became adult 15th–30th January, caged. Good food.
18th February—1 egg-packet cast on the side of the cage.
12th March—1 pair *in copula*.
19th ,, 10 females opened, 2 with large eggs, 5 with small eggs, 3 immature.

The following experiments were carried out in the glass cages which give a higher humidity. All adults were from the field and became adult 15th–30th January.

Glass Cage 23.

14th February—10 pairs caged ; kept in glass cage continuously ; poor food.
1st March—4 males, yellowish.
2nd ,, 1 pair *in copula* for a few hours.
6th ,, 3 pairs *in copula* for a few hours.
7th ,, 2 pairs *in copula* for a few hours.
8th ,, 1 female dead ; large eggs in ovaries.
10th ,, 1 egg-pod ; 1 female dead with large eggs.
11th ,, All *in copula*.
14th ,, 1 egg-pod.
19th ,, 4 egg-pods.

From 11th onwards all pairs were *in copula*. Females opened on 19th ; all with large eggs.

Glass Cage 24.

14th February—10 pairs caged ; kept in glass cage continuously. Good food.
1st March—1 pair coupled but not *in copula* ; some males yellowish.
3rd ,, 1 female dead with small eggs.
4th ,, 1 pair *in copula*.

Glass Cage 24—*cont.*

6th March—4 pairs *in copula*, 1 egg-pod cast on floor.
7th ,, 1 female dead with medium-sized eggs.
10th ,, All pairs *in copula.*
19th ,, 3 egg-pods.

From 10th onwards all pairs were *in copula.* Females opened on 19th ; all with large eggs.

Glass Cage 25.

16th February—10 pairs caged ; kept alternately 4 days in glass cage, 4 days in cage in the open ; good food.
28th February—1 pair dead.
7th March—In glass cage ; 2 pairs paired but not *in copula.*
8th ,, ,, ,, 1 pair *in copula.*
9th ,, In cage in the open ; 1 female dead with large eggs.
10th ,, ,, ,, ,, 1 pair *in copula.*
13th ,, ,, ,, ,, 1 pair *in copula.*
15th ,, In glass cage ; all *in copula.*
16th ,, ,, ,, 1 egg-pod.
17th ,, ,, ,, 1 egg-pod.
19th ,, ,, ,, 1 egg-pod.

Females opened, all with large eggs.

Glass Cage 26.

As Glass Cage 25, but poor food ; caged on the 16th February.
8th March—In glass cage ; 2 pairs *in copula.*
9th ,, In cage in the open ; 1 female dead with large eggs.
10th ,, ,, ,, ,, 1 egg-pod, 1 female dead with large eggs.
11th ,, ,, ,, ,, 1 pair *in copula.*
13th ,, In glass cage ; 1 pair *in copula.*
15th ,, ,, ,, all *in copula.*
17th ,, ,, ,, 2 egg-pods.
19th ,, Females opened, all with large eggs.

Glass Cage 27.

13 females from Cage 1 (which had been without males) put in glass cage on 13th March.
18th March—1 yellow male and 1 brown male (which had been without females) from Cage 2 added.
19th March—Both males *in copula.*

Females opened, 10 with large eggs, 3 with medium-sized eggs.

From 16th to 28th February there was a dry period, so that very high humidities were not obtained in the glass cages. There was moisture on the glass during the night, but during the day the humidity sunk to about 60 in the glass cages with the poor food. This was then moistened, after which the humidity was nearly the same as that in the cages with good food, and did not sink below 70.

After 1st March, when the outside atmosphere became moister, there was moisture on the glass of the cages all the time, and they had to be wiped periodically with a cloth.

Approximately speaking, the average relative humidity in the glass cages was 85 per cent. from 16th to 28th February and 95 per cent. or more from 1st to 17th March. It is doubtful if *Schistocerca* could live at this latter high humidity for long.

The temperature in the glass cages was less than that of the cages in the open, as the glass cages were in the shade, and not sheltered from the wind. The maximum temperature was lower than and the minimum higher than those in the open.

The results of these experiments are discussed below (see page 61).

Weather at Khor Ashat in the Season 1934–35 (fig. 6).

As has been remarked earlier, the temperature range of the Red Sea coast is less than that of inland places owing to the influence of the sea. The climate is thus technically milder, although the hottest time of the year on the coast is much more unpleasant for human beings than the hottest period inland, owing to the higher humidity and absence of wind at this period.

In the winter the northern parts are normally colder than the southern. In the 1934–35 winter the weather at Ashat was cool for the most part with screen maximum temperatures under 30°. Part of February was still colder with screen minimum temperatures under 20°.

In Figure 6 only the screen maxima and minima, and the average daily temperature calculated from the thermograph, are given. The maximum temperature of the soil surface in the sun was 40°–50° for most of the season but it rose to 53° on 11th November, and was below 40° for a few days in December. The grass minimum was usually 1°–2° lower than the screen minimum. The average temperature 4 inches below the sunny soil surface was usually about 2° higher than the average 7 inches above the ground in the shade.

When Ashat was reached at the beginning of November, it was the end of the late summer weather. At this time the wind would drop after sunset, and start to blow gently from the N.W. at some time during the night. The relative humidity at dawn was about 60 per cent., after which it would drop rapidly to about 30 per cent. The N.W. wind dropped at about 10.00, and a stronger N.E. wind arose at about 12.00 when the relative humidity would rise to about 60 per cent., increasing slightly towards sunset at 17.00 hours. The sky was at this time clear, except for slight clouds over the hills.

On 9th November, the weather became cloudy with drops of rain, and the humidity increased. The first heavy rain fell on 12th November, when a huge storm cloud came up from the south with much thunder, resembling a summer rainstorm. Subsequent rain came in a milder fashion without much wind or thunder, and without storm clouds appearing to come from any particular direction. Rain fell most days from 12th to 23rd November and this was the end of the heavy rains, though as may be seen from Figure 2 rain fell during many days up to the end of the season.

When rain was falling the wind was usually from the north. The N.W. wind in the morning and the N.E. wind in the afternoon are doubtless ordinary land and sea breezes caused by the more rapid changes of temperature on land.

On 24th November there was a heavy dew at night for the first time. This continued up to 6th December. If the wind dropped completely at night, the dew was very heavy, penetrating about half an inch into the ground. On 7th December the wind became more northerly, and often continued blowing at night, and the weather was colder and drier. This period ended on 12th December, when more rain fell but in small quantities up to 23rd December, and the humidity was higher. From then until 9th January, there was no measurable rainfall, and the humidity was lower, without dew most nights. On 10th–12th January there was drizzling rain and on several days between 19th January and 2nd February. On none of these days was the fall sufficient to penetrate the soil more than 1 inch, and it dried up rapidly. The humidity remained fairly low, considering the hours in which rain fell. This was probably due to the wind coming from the north during the day. There was no dew most nights. The periods 3rd–13th February and 19th–26th were rainless, and the humidity was the lowest of the season being below 70 per cent. From 26th February till 20th March, there were drops of rain on several days, and the humidity rose again.

The term humidity refers to the average relative humidity calculated from the graph of the recording instrument. On a day without heavy rain, the humidity usually reached its maximum at about 22.00 hours, being usually between 80–100 per cent. It might remain here till dawn (6.00), or it might start to fall before dawn, if the wind rose ; it reached its minimum of about 60 per cent. at about noon, after which it began to rise with the sea breeze. In the driest periods the difference was usually that the maximum was lower, and that the humidity did not remain at its maximum for long. This higher humidity of the coast as compared with that of the inland part of the distribution-area of *Schistocerca gregaria* is much greater than the differences in temperature. It is indeed remarkable that an insect which can survive the Kordofan summer where the average relative humidity is often as low as 8 per cent. can also exist under the moist coastal conditions.

In Kordofan (1934) the old solitary adults which had spent the dry season (October–May) in a sexually immature condition began to develop eggs when the relative humidity rose to 40 per cent. with the arrival of the south wind. Although the rainy season had arrived, no effective rains had fallen at the station (Um Darag), and only places 15 miles away had been rained on. At Um Darag, locusts did not lay eggs in the field, as the ground was dry, until the first effective rain had fallen. At places where rain fell earlier, eggs were laid earlier, although the locusts had matured at the same time as at Um Darag. In this case the increase of atmospheric humidity seemed to be the factor inducing egg-development. The author has never been able to induce mature *Schistocerca* females to oviposit in dry sand, as they prefer, in this case, to cast the eggs on the surface.

In the case of the locusts taken from the Red Sea coast to Khartoum in May 1934 (see page 47), the first copulation was observed on the afternoon of the first rainy day. Next day some eggs were laid. In other words the locusts must have developed the eggs in their ovaries before the rain came, but lacked the stimulus to copulate. Ramachandra Rao in a recent paper (1934) quotes various similar examples from the field in which oviposition took place immediately following the first heavy rain. The eggs must have been developed before the rain. Copulation is not mentioned.

In the cage experiments on the young adults at Ashat (page 46) the first copulation took place on 12th March, on which day the humidity was no higher than on several days preceding ; but very few locusts copulated at all, and very few eggs were laid. In the glass cages, copulation occurred later than might have been expected, if high humidity was the only factor. The females may not have been ready earlier. The quality of food seemed to have no effect in these experiments.

In the experiments with the original adults in November (page 53), the first copulation in cages in the open took place on 20th November, on which day the humidity was lower than on some days during the preceding week. In the glass cage the first copulation took place on 16th November—only four days earlier than in the dry cages. The females again, may not have been ready.

As regards sunlight as an influencing factor, the locusts in Khartoum, in June 1934, first copulated in a room with closed shutters. Dr. A. G. Hamilton in his laboratory studies in London (unpublished) found that *Schistocerca* adults of 17 days old copulated and later oviposited when kept at a humidity of 65–75 per cent. On this basis all the young adults on the Red Sea coast should have copulated and laid eggs by the middle of March.

It may be argued that the humidity experienced by locusts in the field is not the same as that registered by the recording instrument, 7 inches from the soil surface in the shade. The following figures, however, show that the differences in relative humidity in various habitats on the Red Sea coast are not large.

Although we do not know the exact reason, there is no doubt that rainfall is necessary before oviposition can begin. Once one batch of eggs has been laid, further batches may be laid provided that the soil is moist. It need not be moist on the surface ; at Ashat, in March 1934, females were observed ovipositing in sand of which the upper inch was a dry crust, and moist sand was found only at 2 inches depth.

TABLE III.

Egaiet, 23*rd February* 1934.

Time	Air temperature		Relative humidity	
	A	B	A	B
06·00	16·0	16·1	55	57
09·00	22·1	22·3	44	46
13·00	25·3	25·3	43	46
17·15	21·6	21·9	49	49

A=1 ft. from ground among dry *dukhn* at edge of delta.
B=1 ft. from ground among green *dukhn* in khor-bed in middle of delta.

TABLE IV.

Hamasheb, 23*rd April* 1934.

Time	Air temperature			Relative humidity		
	A	B	C	A	B	C
5·30	21·2	21·8	21·8	74	72	72
8·15	31·7	30·0	30·1	47	50	51
12·00	34·9	34·0	32·4	42	44	46
16·00	31·5	30·8	30·0	41	42	42
18·00	26·7	26·7	26·5	66	64	66

A=1 ft. from ground among green *Pennisetum*
B=1 ft. ,, ,, on bare dune.
C=4 ft. ,, ,, ,, ,,

At Hamasheb (fig. 5) there was heavy rain at the end of January 1935. On 11th March, nearly all females examined were mature and copulating. At Ashat the last heavy rain fell on 7th December 1935, and the majority of young adults did not lay eggs.

The coast south of Tokar received heavy rains from early November 1934, till the end of January 1935, and there were 15 mm. in February and 13 mm. in March 1935. There was an outbreak of *congregans* in April 1935 in this region. Marching hoppers were found near Aqiq and Adobana and south of the latter place. These bands doubtless originated in the cultivated dune areas near the sea. The District Commissioner, Tokar, arranged for their destruction. In 1933–34 season, the rains

TABLE V.

Khor Ashat, 16*th December* 1934.

Time	Pos. I T°	Pos. II			Pos. III T°	Pos. IV T°	Pos. V			Pos. VI			Pos. VII		Pos. VIII		Pos. IX T°	Weather
		T°	A.T°	R.H.			T°	A.T°	R.H.	T°	A.T°	R.H.	A.T°	R.H.	A.T°	R.H.		
6.00	21·0	20·9	21·7	93	21·5	20·3	21·1	21·5	94	21·3	21·8	93	22·0	92	21·6	94	24·0	Sunrise. Dew on ground.
7.30	25·6	25·3	25·0	78	27·8	25·2	25·2	25·1	77	25·0	25·1	77	25·1	77	25·3	77	24·3	Cloudy.
9.00	29·0	27·8	27·2	72	30·8	27·8	27·1	27·3	72	26·8	27·3	72	27·2	72	27·0	72	25·2	Cloudy.
10.30	35·7	32·1	30·3	66	35·2	31·1	29·8	29·3	67	28·8	28·5	69	27.6	73	28·8	68	26·8	Light clouds.
12.00	41·7	35·3	29·6	67	37·2	33·8	31·3	29·8	66	29·7	29·2	68	28·6	70	29·0	67	29·2	Light clouds.
13.30	42·0	35·0	29·0	69	41·9	34·4	31·8	29·0	69	29·3	28·8	69	28·2	71	29·0	70	31·3	Sunny.
15.00	34·8	32·0	28·0	73	37·5	31·3	29·9	27·2	75	28·8	27·0	76	26·9	78	27·0	77	31·8	Sunny.
17.30	28·0	26·0	25·8	80	27·9	25·0	25·3	25·7	81	25·6	25·7	81	25·7	81	25·6	81	30·8	Sunset, cloudy.

T° = Temperature of mercury thermometer; horizontal.
A.T° = Air temperature, dry bulb of whirling hygrometer.
R.H. = Relative humidity; whirling hygrometer.
Position I = Bare soil temperature; bulb just covered with soil.
,, II = Bulb just not touching surface of bare sand.
,, III = As II, but on sloping bank, facing south, sheltered from wind.
,, IV = Bulb resting on short grass, one inch from ground.
,, V = Six inches from bare ground.
,, VI = Twenty-four inches from bare ground.
,, VII = Forty-eight inches from bare ground.
,, VIII = In the middle of *Suaeda* bush, eighteen inches from ground.
,, IX = Four inches below surface of sand.

All positions were in the sun except for VIII.

south-east of Tokar continued till March, but they had not started till the end of December, which accounts for an outbreak not having occurred there in April 1934 ; because the first eggs could not have been laid till January, and the first generation hoppers could not have become adult till the first half of March, so that the last rain fell while they were still, for the most part, in the hopper stage.

The outbreak in 1925–26 season which was seen by Johnston (1926) was apparently confined to the Arbaat khors north of Port Sudan. These khors did not produce an outbreak in 1933–34 or 1934–35. The rainfall figures for Port Sudan for the winter of 1925–26 show 19·4 mm. in October, 127·9 in November, 272·7 in December, 2·2 in January and 0·2 in February. It seems hard to explain the maturation of the young adults at, say, the end of January on these figures. But there may well have been heavy rain at Arbaat in February or March 1926, while none fell at Port Sudan. For that season (1925–26) rainfall figures for Suakin are also high but less than Port Sudan. For Tokar and Aqiq the figures are lower than normal. The figures for Tokar are probably less than places nearer the sea, *e.g.* Hamasheb.

According to the records accumulated in the Imperial Institute of Entomology and communicated to the author by Dr. Uvarov, an outbreak of *Schistocerca gregaria* in the Sudanese area began in 1912 when swarms appeared in Eritrea and Italian Somaliland. In September 1913, some swarms were present in the interior of the Sudan, and in Kenya ; in 1914, swarms appeared in Egypt. By 1915 the outbreak had developed on a very large scale. It will be seen from the chart (fig. 6) that the beginning of this outbreak also coincided with two exceptionally rainy winters on the Red Sea coast.

Connection of Outbreak Centres with Dukhn Cultivation.

It will be remembered that, in the 1933–34 season, phase *congregans* hoppers were produced only in and near rain-grown *dukhn* on soft sand (see page 56). We shall now proceed to analyse the conditions in such cultivated spots, and how they differ from uncultivated areas.

1. The same areas are not necessarily cultivated every year. The chief factor which determines whether sowing is to take place in a given area is rainfall. (We are not now considering areas which receive regular floods such as the Baraka delta.) In a year with good rains larger areas are cultivated.

2. Rain *dukhn* cultivation is always on a soil with a loose surface of sand, or sand and silt mixture near the Baraka delta, and there are nearly always loose dunes round and among the crop. This loose sand is sometimes natural, as in the case of Hamasheb, or results from the processes of cultivation, as at Ashat. The beds of some khors are naturally composed of loose sand on the surface, but the area outside the khor-bed had its soil artificially loosened. The characters which distinguish loose, sandy soil from hard sand or clay are :—(*a*) It dries up more slowly, with the result that moist sand is nearer to the surface for a longer period than in the case of hard soils ; this may be accentuated by wind blowing the dry sand away and exposing the moist surface in places. (*b*) *Heliotropium undulatum* grows on it in masses, where it is not weeded ; this plant is almost evergreen in such conditions.

3. The *dukhn* and most weeds among it remain green after the surrounding vegetation has withered. This is partly due to the soft sand, as it is most marked in a place like Ashat where the surrounding country is hard.

The meteorological data in Tables I and II make it unlikely that local climatic conditions are of much importance in the problem of why the largest numbers of locusts occurred only in and near cultivation.

The reason that seems most probable is that of food-plants, as the vegetation remains green for longer. Round the loose dunes at Ashat, in the area of old cultivation the *Heliotropium* remained green until March 1935, but there was no *dukhn* and adults eat the latter plant to a large extent, although hoppers prefer the former. In April 1934, these loose dunes were visited, but *congregans* had not occurred there, because the hoppers were not sufficiently numerous, although bands of hoppers were present at various places in the cultivation.

In the 1933–34 season a concentration of young adults into the green *dukhn* from areas outside was suspected, particularly at Khor Arbaat. In the 1934–35 season this idea was not confirmed, as the original adults were most numerous among the *dukhn* ; and, where the young adults were at all numerous outside the cultivation, *i.e.* in the area of old cultivation, they were still present in March.

During February 973 young adults were marked on the pronotum with enamel paint and released at various places outside the cultivation. Unfortunately only 5 of these were recovered.

No.	Date released	Where released	Date recovered	Where recovered	Remarks
1	10th Feb.	*Panicum* dune near camp	20th Feb.	On same dune	Male
2	10th Feb.	,, ,,	23rd Feb.	In southern cultivation	Female mature when recovered
3	11th–12th Feb.	*Suaeda* dunes near camp	19th Feb.	Cultivation near road	,, ,,
4	,,	,, ,,	,,	Middle of cultivation	Female immature
5	14th Feb.	Old cultivation	17th Mar.	,, ,,	Male

From these examples nothing can be deduced. No. 3 flew a considerable distance. Solitary locusts, when disturbed, usually make a low flight of up to 50 yards, and then alight. If one is continually disturbed, it may finally fly higher and then travel for some distance.

It may be that more locusts can survive the dry season in a cultivated area than outside it, and that there is always a higher population of solitary locusts in such areas.

Summary and Conclusions.

1. An ecological description of the Red Sea coast of the Anglo-Egyptian Sudan is given, with special reference to the occurrence of the solitary phase of *Schistocerca gregaria* in its different parts and zones.

2. The greatest numbers of solitary Desert locusts were found amongst rain-grown *dukhn* (*Pennisetum typhoideum*, Rich.) cultivated in the *Suaeda* belt of the coast, near the sea.

3. The factors responsible for the higher population of solitary locusts among the cultivation are probably the soil consisting of soft loose sand, and the more or less evergreen condition of the weeds on cultivated plots. It appears possible, however, that in some localities with naturally loose sandy soil all areas suitable for vegetation are cultivated, and in this case the cultivation in itself is not of primary importance.

4. Incipient outbreaks were observed in the type of cultivated areas described above in 1933–34, and again in 1934–35 winter seasons. Hoppers of the phase *congregans* were found mostly on a weed, *Heliotropium undulatum*, which is preferred by young hoppers to other food-plants, and seemed to act as a concentrating factor for the hoppers. No hoppers of the ph. *congregans* were found on clean cultivation where this weed was absent.

5. The chief factor determining the commencement of an outbreak seems to be heavy winter rains (over 240 mm. during the season), starting early (end of October) and continuing late (end of February), which allows for the development of two successive winter generations, as follows :—(*a*) Early maturation of old adults (November) ; (*b*) plentiful oviposition of old adults (November–December) ; (*c*) hoppers beginning to emerge (end of November) ; (*d*) hoppers beginning to become adult (early January) ; (*e*) majority of hoppers adult (end January) ; (*f*) these young adults remaining among *dukhn* in a fairly crowded condition (February) ; (*g*) young adults maturing (end February) ; (*h*) young adults ovipositing (March) ; (*i*) hoppers hatching (end of March–April) ; (*j*) young hoppers crowded on *Heliotropium*, assuming *congregans* coloration and later forming marching bands (April) ; (*k*) emigration of young flying swarms (May).

6. The exact cause of the rapid maturation of young adults of the first winter generation has not been discovered, although a short period of very high humidity seems to have some effect. There is no doubt that late rains are necessary for most adults to mature and oviposit in the field.

7. The Red Sea coast of the Sudan is distinguished from the interior of that country by its higher air humidity, by winter rains, and by the fact that the rainy season can extend for a longer time than the summer rainy period inland. The northern parts of the coast, north of the latitude 20°N., are less likely to produce outbreaks only because heavy and prolonged rains are unlikely to occur there.

8. General conditions in Eritrea, south of the Sudanese border, are such that some outbreak areas should be expected to exist there.

9. It appears probable that the Arabian coast of the Red Sea also contains some outbreak areas. As regards inland parts of Arabia, their climate, the distribution and the life-cycle of the solitary locusts there, are too little known to estimate the possibility of the existence of outbreak areas, until a special investigation is made.

10. The results of the investigations on the Red Sea coast put under suspicion of harbouring outbreak areas of the Desert locust all those parts of the sea-coasts of Africa and Asia which may obtain in some years winter rainfall of not less than 240 mm. extending for a period sufficiently long to allow for the development of two successive winter generations of the locust.

Acknowledgments.

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References.

JOHNSTON, H. B. (1926). A further contribution to our knowledge of the bionomics and control of the Migratory Locust, *Schistocerca gregaria*, Forsk. (*peregrina*, Oliv.), in the Sudan.—Wellcome Trop. Res. Lab. Ent. Sect., Bull. **22,** 14 pp., 1 map.

MAXWELL-DARLING, R. C. (1934). The solitary phase of *Schistocerca gregaria*, Forsk., in North-Eastern Kordofan (Anglo-Egyptian Sudan).—Bull. Ent. Res. **25,** pp. 63–83, 5 figs., 2 pls.

RAMACHANDRA RAO, Y. (1934). The life-cycle, particularly sexual maturation, in relation to climatic and other factors and methods of study.—Proc. Third Intern. Locust Conf., London. H.M.S.O., London, Cmd. 4725, pp. 67–73.

EXPLANATION OF PLATE I.

Fig. 1. Unsown patch in the middle of *dukhn* cultivation. Two *Suaeda* bushes can be seen, and masses of *Heliotropium undulatum* on the ground. The *dukhn* may be seen in the background. This was an outbreak centre in 1933–34.

,, 2. The tree belt of the coastal plain near the hills. Many *Acacia tortilis* trees are visible. The undershrub in the foreground is *Cadaba* sp., and the vegetation on the hard ground is *Aristida mutabilis* and *Zygophyllum simplex*.

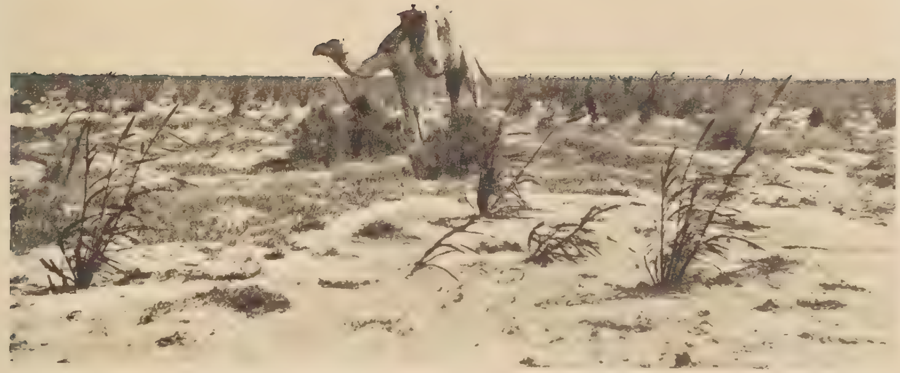

Fig. 1

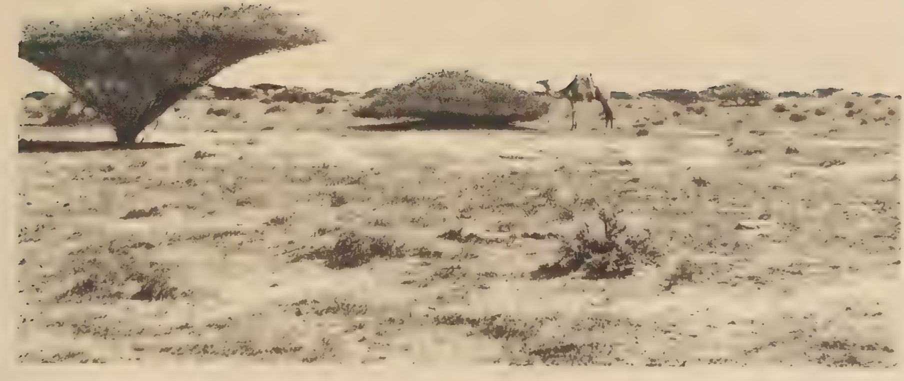

Fig. 2.

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EXPLANATION OF PLATE II.

Fig. 1. The area of old cultivation at Khor Ashat. The sand is loose and the vegetation consists of *Heliotropium*, *Brachiaria* and *Commellina*. Some *Capparis decidua* bushes are in the distance.

,, 2. The hard *Suaeda* dunes. Many *Suaeda* bushes and dense patches of *Chloris virgata* on the ground.

Fig. 1.

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Fig. 2.

A SHORT RECONNAISSANCE OF NORTHERN DARFUR (ANGLO-EGYPTIAN SUDAN) WITH REGARD TO *SCHISTOCERCA GREGARIA*, FORSK.

By R. C. Maxwell-Darling, B.A.(Cantab.)

A short tour of northern Darfur was made by the author, on behalf of the Imperial Institute of Entomology, with the object of observing the solitary *Schistocerca* population, comparing it with that of northern Kordofan, and looking for any factors which might indicate the presence of potential outbreak centres of the desert locust.

The author travelled from El Obeid in Kordofan Province to Um Kedada by car, and thence northwards by camel. The route followed is shown on the map. The journey from Um Kedada northwards and back to Fasher via Kutum took 47 days, from 21st August to 7th October 1934.

Description of Country and Vegetation.

The land round Um Kedada consists of fairly open goz, and there is a fair amount of cultivations. The term "goz" means sand-hills the soil of which is fixed by vegetation, while it may be secondarily loosened by clearing and cultivation (Maxwell-Darling, 1934). These gozes are doubtless similar to the "old dunes" referred to by some authors.

From Um Kedada northwards one passes through a short stretch of low sandstone hills with gozes among them, and hard sand and clay in the low-lying parts. There are villages for the first 20 miles with *Pennisetum* cultivation and a little cotton. The country is all fairly thickly wooded except where the ground is cleared for cultivation. The commonest trees and bushes are *Acacia arabica*, Willd., *A. mellifera*, Benth., *Maerua crassifolia*, Forsk., *Odina* sp., *Premna resinosa*, Schauer, and *Commiphora* sp. The ground vegetation is composed of *Cenchrus catharticus*, Del., *Tephrosia nubica*, Baker, *T. incana*, Graham, *Pavonia kotschyi*, Hochst., and various herbs and grasses. On the hard ground *Indigofera suaveolens*, Jaub. & Spach., *Cymbopogon proximus*, Stapf, and *Antephora elegans*, Schrad., occur.

After leaving this area, there was no more cultivation except for one small village near Jebel Taganor and a small quantity round Jebel Meidob.

Northwards of the settled area near Um Kedada, the country consists of wooded gozes. The trees are at first dense, so that it is sometimes difficult to ride between them. Later most of the species mentioned above disappear, and the thickets consist almost entirely of *Acacia mellifera* and *Commiphora*, in places as dense as an orchard, and in places more open.

The sand surface is firm and dark in colour and bears the perennials, *Aristida plumosa*, Linn., *A. stipoides*, Lam., *Pavonia kotschyi*, and a little *Pycreus mundtii*, Nees; and the following annuals, *Blepharis linariaefolia*, Pers., *Monsonia senegalensis*, Guill., *Tragus racemosus*, All., *Latipes senegalensis*, Kunth., *Schmidtia pappophoroides*, Steud., *Aristida adscensionis*, Linn., and, in patches, *Cenchrus catharticus*.

These gozes differ from those in Kordofan described by the author (1934) in the following points:—(i) The Darfur gozes are more wooded; (ii) *Panicum turgidum*, *Leptadenia spartium* and *Crotalaria thebaica*, which are abundant on the Kordofan gozes, are practically absent in Darfur at the same latitude; (iii) *Aristida plumosa*

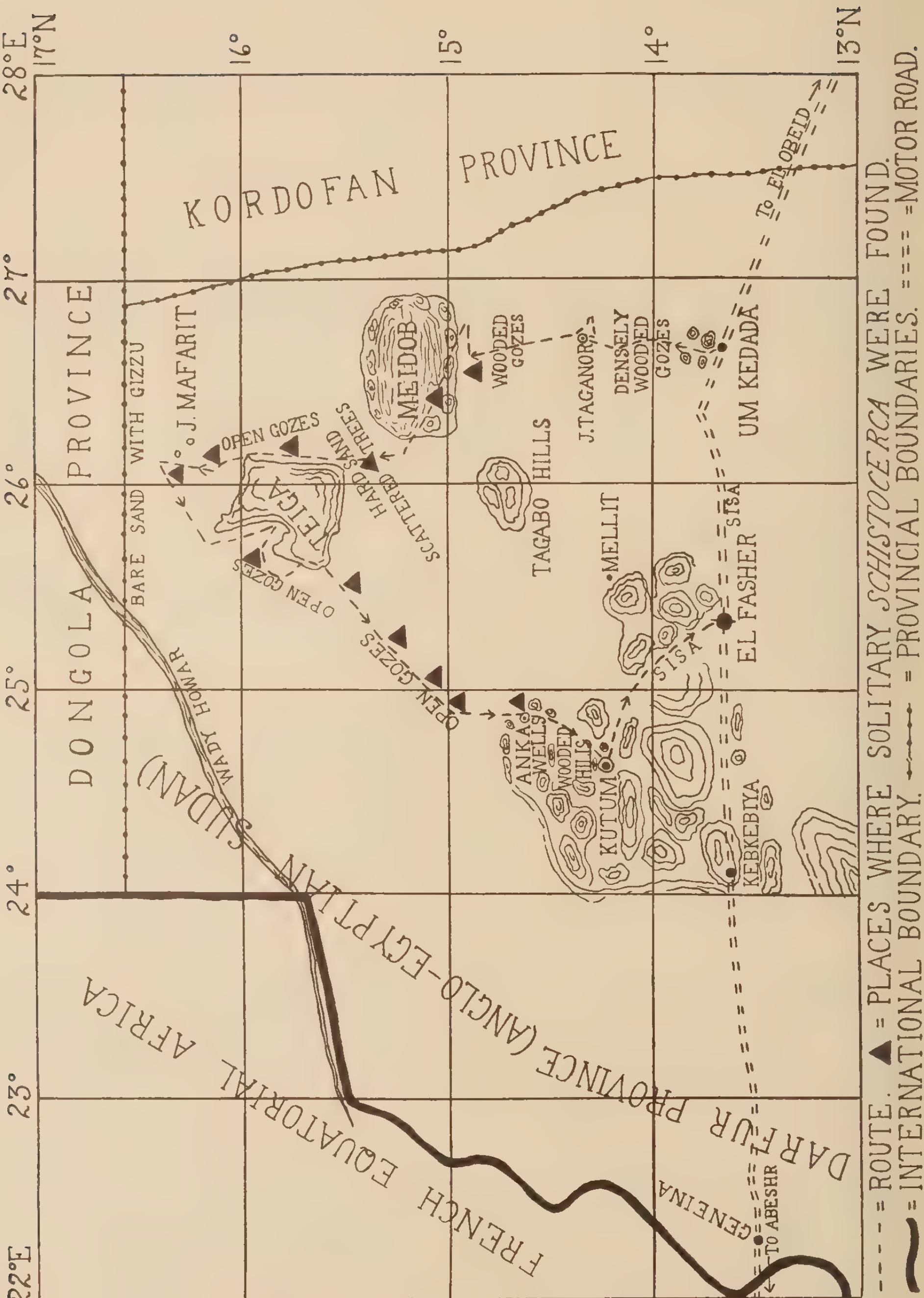
28°E
17°N
16°
15°
14°
13°N
27°
26°
25°
24°
23°
22°E
KORDOFAN PROVINCE
DONGOLA PROVINCE
BARE SAND WITH GIZZU
J. MAFARIT
OPEN GOZES
TEIGA
HARD SAND
SCATTERED TREES
MEIDOB
WOODED GOZES
J. TAGANORO
DENSELY WOODED GOZES
UM KEDADA
To EL OBEID
TAGABO HILLS
MELLIT
SISA
EL FASHER
SISA
ANKA WELLS
WOODED HILLS
KUTUM
KEBKEBIYA
WADY HOWAR
DARFUR PROVINCE (ANGLO-EGYPTIAN SUDAN)
FRENCH EQUATORIAL AFRICA
GENEINA
TO ABESHR
- - - = ROUTE. ▲ = PLACES WHERE SOLITARY SCHISTOCERCA WERE FOUND.
= INTERNATIONAL BOUNDARY. = PROVINCIAL BOUNDARIES. ==== = MOTOR ROAD.

Fig. 1. Sketch-map of Northern Darfur.

and *Blepharis* are common on the Darfur gozes, but are not abundant in Kordofan. The causal factor of these differences is probably the rarity of cultivation on these Darfur gozes. Most of the Kordofan gozes have been cultivated at one time or another with consequent clearing of the trees, loosening of the sand and alteration of the vegetation. Another possible cause is that large herds of domestic animals have been grazing regularly in Darfur at these latitudes only for the last 18 years, whereas such grazing has taken place in Kordofan for a much longer period.

North of Jebel Taganor the country becomes more widely undulating, the sand is harder and the trees more scattered.

Round Jebel Meidob, which is a high volcanic range of hills, is *sisa* ground with khors, clay wadies and patches of stony ground. There are areas of goz among the hills. These gozes are more like those in Kordofan with abundance of *Aristida sieberiana*, Trin., and *Bouchea marrubifolia*, Schauer. *Panicum turgidum* was seen for the first time in Meidob khors. There are villages at Jebel Meidob but the area of cultivation is small, as the chief industry is sheep-rearing.

North-west of Meidob, the ground is hard sand with several large khors. Trees become few, and several new plants make their appearance ; an undershrub with a strong smell, *Barleria candida*, Nees, two perennial grasses, and some other undershrubs.

Jebel Teiga is a low plateau covering a large area. It has a few deep rock-pools which provide a water-supply during the rains and early winter. Between Jebel Meidob and Bir Natrun (latitude 18°N.) there are no wells.

North of Teiga, trees and bushes disappear and downs of red sand stretch away northwards as far as the eye can see. The ground is at first densely covered with *Cenchrus catharticus*, which gets less as one goes north and is replaced by *Indigofera arenaria*, A. Rich., *Fagonia cretica*, Linn., *Blepharis*, *Bouchea* with some *Pycreus*, *A. sieberiana* and *Panicum*. This stretch is soon passed and the *gizzu* area proper is reached.

The Arabic word *gizzu* refers to the vegetation which springs up late in the northern deserts, and lasts throughout the winter if the rains (July–September) have been good. Herds of camels are pastured in the *gizzu* throughout the winter when, grazing on the green vegetation, they do not require to drink.

This northern area is the southern edge of the Libyan Desert and consists of bare rolling downs of rather coarse red sand sometimes forming wind-blown dunes. From many miles away a darker patch may be seen which is an area of *gizzu* vegetation. In September this was very lush where it occurred, whereas the vegetation to the south of Meidob was withering at this time. The commonest plants were *Aristida papposa*, Trin. & Rupr. (a tussock grass), *Tribulus* spp., *Indigofera arenaria*, *Citrullus colocynthus* and *Heliotropium undulatum*, Vahl., which are more or less procumbent plants, and some *Panicum* and *Farsetia longisiliqua*, Dec. Although some of these procumbent plants straggle over a fairly large area of sand, the vegetation is not dense, and there is bare sand between the plants. There are a few low-lying spots where clay is exposed among the sand.

This northern country had been rained upon during the latter half of August. Whether it received rain before that date is not known, but natives say that the rains in this area are usually late, and sometimes absent. At the end of September the plants mentioned above were all well grown, but *Neurada procumbens*, Linn., was only just beginning to germinate in large quantities. *Indigofera bracteolata*, D.C., which was very common in the *gizzu* of north-eastern Kordofan in January 1933, was not recognised by the writer in Darfur. It may be that it germinates late, but some small plants were stated to belong to that species by the natives.

No water channels were seen in this area, except in the neighbourhood of rocky hills, as any rain falling soaks into the sand. The distance that can be travelled north and west of Teiga is limited by the water-supply. As the above vegetation is the last type before pure desert is reached, there was little to be gained by proceeding farther towards Bir Natrun.

South-west of Teiga there are broadly undulating gozes with no trees or bushes except in depressions. The principal ground vegetation is composed of *Aristida plumosa*, *Blepharis* and *Schmidtia pappophoroides*. After about 30 miles the two latter annuals are largely replaced by a perennial, *Sporobulus* sp., and a procumbent annual, *Monsonia senegalensis*, Guill. These gozes continue as far as Wady Anka, with occasional stony ridges among them.

From Anka the land rises slowly towards Kutum, which lies at an altitude of 3,800 ft. above sea-level. There are scattered rocky hills, and the land among them consists partly of firm goz with *Commiphora* trees, and partly of rock with many khors. The trees become more numerous towards Kutum.

South of Anka, the country is settled, though the villages are rather scattered.

Between Kutum and El Fasher there is at first a small area of cultivated goz that gives way to clay *sisa* which continues most of the way to El Fasher. This town is on a sandy patch. Eastwards of it the *sisa* continues for some 40 miles, where it is replaced by the gozes towards Um Kedada.

Occurrence of Schistocerca.

No swarms of *Schistocerca* were seen or heard of in 1934, and very few of *Locusta*. In 1932 there had been some breeding by swarms of *Schistocerca* in the Meidob-Kutum area, and also to a lesser extent in 1933. The following remarks apply to solitary individuals.

At the time of leaving Um Kedada (20th August) the majority of solitary locusts, if any were present, would have been in the hopper stage. As the solitary hoppers are very inconspicuous, failure to find any in a certain place cannot be taken to mean that they are absent.

At each encampment, two men would walk about slowly, stirring the vegetation with a stick. If any movement was seen, a closer inspection was made, and the hopper identified.

From Um Kedada northwards, no *Schistocerca* were found, until the Kabbabish encampment about 10 miles south of Meidob was reached. Here was a gentle slope of hardish sand running down to a clay wady. There were scattered trees 50 to 150 yards apart, with a dense growth of *Cenchrus*, some patches of bare sand and some *Bouchea* and *Pavonia*. In this area about five green hoppers could be found by one man in an hour.

In the gozes among the Meidob foothills similar numbers of hoppers were found and there were a few young adults.

Between Meidob and Teiga, odd adults were seen as soon as the Meidob clay was passed.

The largest numbers met with were on the open gozes north of Teiga before the *gizzu* was reached. In this area 22 adults were seen in about 10 miles.

Farther north small numbers were found in all the areas where there was green *gizzu* vegetation, and also occasionally on bare stretches.

There were small numbers on the open gozes between Teiga and Anka, where 1–5 adults might be seen in 10 miles. On gozes just to the south of Anka, one adult was found, after which no more were seen.

The cultivation and surrounding gozes at Um Kedada were again searched on 12th October. No *Schistocerca* were found.

Climate.

The climate of Darfur is similar to that of Kordofan, except that it is somewhat cooler, as the land is higher. The country to the north of Meidob is about 2,000 ft. above sea-level. The rainy season, as in all the northern Sudan except the Red Sea Coast, falls in the summer (July–September).

There was heavy rain from 20th to 28th August 1934, and the average relative humidity was over 70 per cent. From then until 6th September there were light showers on several days and the relative humidity gradually fell to 40 per cent. From 6th September there was no more rain, except for drops on 1st October, and the average relative humidity was 20–32 per cent.

Maximum temperatures after the rains had ceased were 32–35°C. during the first half of September. In the *gizzu* area, during the latter half of September, the temperature had sunk to 17·7°C. at dawn one day, and the maximum was never higher than 34°C.

Conclusions.

The wooded gozes of northern Darfur had, as was to be expected, a smaller population of solitary *Schistocerca* than the more open gozes in Kordofan, which have been cultivated at some period. Where the gozes were open, to the north of Teiga, the population was higher. It may be said, therefore, that Darfur is no more suitable for the solitary phase of *Schistocerca* than is Kordofan.

On the Red Sea coast where the production of swarms in the outbreak centres has been studied (Maxwell-Darling, 1936, above), there seem to be two main factors concerned :—

(i) The sexual maturation of the young adults of the first generation during the same season. If they remain immature until the next rainy season, the majority die and the population remains more or less constant.

(ii) The fact that the young adults do not scatter but remain concentrated in certain localities (*i.e.* cultivated areas) so that the young hoppers of the 2nd generation are fairly crowded when they hatch.

The beginning of oviposition by the old adults, which had remained during the summer in an immature condition, is determined by the first rains usually in November, as the winter is the rainy season on the Red Sea Coast. Their offspring are adult by the end of January, and if the rains are prolonged until the end of February, these young adults will become sexually mature, and their offspring will probably form swarms if uncontrolled.

In the western Sudan the hoppers usually become adult during September, according to when the first rains fall. The young adults on the Red Sea coast usually remained immature for a month, even if the rains were continuing. We may assume, therefore, that the young solitary adults in Kordofan or Darfur require certain conditions during October in order to mature during the same season.

The latter half of September and October is the *darrat* season, when the rains proper are over, the weather gets hotter and the atmospheric humidity lower. Rain in October is not very rare, but it usually takes the form of a short storm, and the atmospheric humidity rises for a short time only. As it is apparently increased atmospheric humidity which causes sexual maturation, it seems unlikely that the young adults could mature in the same season.

On the gozes which are suitable for solitary *Schistocerca*, the conditions are rather uniform. There are, therefore, no factors to keep the locusts in a restricted space, such as occurs on the Red Sea littoral. In the *gizzu* area farther north, fresh vegetation will be coming up over wide areas if there have been late rains. Here again there is nothing to keep the locusts in such concentration as would result in crowded hoppers, in the event of oviposition taking place.

In the light of our present information, therefore, it would seem improbable that there are potential outbreak centres of *Schistocerca gregaria* in the Anglo-Egyptian Sudan other than those on the Red Sea coast, which have been discussed in another paper (Maxwell-Darling, 1936, above).

Reference.

Maxwell-Darling, R. C. (1934). The solitary phase of *Schistocerca gregaria*, Forsk., in North-Eastern Kordofan (Anglo-Egyptian Sudan).—Bull. Ent. Res. **25** pp. 63–83, 5 figs., 2 pls.

OBSERVATIONS ON RATE OF GROWTH, COLORATION, AND THE ABNORMAL SIX-INSTAR LIFE-CYCLE IN *LOCUSTA MIGRATORIA MIGRATORIOIDES*, R. &. F.

By K. H. L. Key, M.Sc., Ph.D., D.I.C.

In the course of some experiments on behaviour in *Locusta migratoria migratorioides*, R. & F., which necessitated keeping the insects under very constant and carefully controlled conditions of temperature and relative humidity, the opportunity was taken of making certain miscellaneous biological observations upon this locust.

1. Experimental Conditions.

The material used was derived from a stock which has been bred for over ten generations by the Imperial Institute of Entomology in its research laboratory in London. The insects came in the first place from Central Africa. Batches of just-hatched hoppers were received from the Institute as they became available, and were reared in a constant temperature room which maintained a temperature of 27°C. day and night, the greatest variation being about 0·5°C., and the average daily variation about 0·1°C. Light intensity was low, about 5 ft.-candles, and constant day and night, but varied slightly in different parts of the room, and therefore for different insects. Each insect was kept isolated, from the time of hatching, in a desiccator about 6 cm. high and 10 cm. in diameter, and was fed once a day with cut grass.

Some insects were kept under wet, some under dry, conditions, by placing either water or $CaCl_2$ in the bottom of the desiccator, and using a well-fitting and slightly greased lid. In this way relative humidities varying between 5 per cent. and 20 per cent. were obtained. It is impossible to maintain a constant low humidity in cages containing insects which have to be fed on green food, but if not too much food is given, this soon dries up, and the humidity falls within a few hours to its original low value. Insects " kept dry " in the following account, then, have been kept at a humidity of, on the average, 5–10 per cent., with a rise about once a day to about 50 per cent. for a few hours. The relative humidity in the " wet " cages reached over 99 per cent., and must frequently have been at saturation. The problem of ventilating these cages was solved by removing each lid for an hour each day at the time of feeding ; the original humidity was quickly resumed when the lid was replaced.

Under such completely isolated conditions it is clear that only phase *solitaria* could develop, and this was confirmed by the records of the colours of the hoppers and the structural characteristics of the adults, of which records were kept.

In some of the experiments black, white or green cardboard covers were placed round the outside of the desiccators, the light entering at the top, and in this way the effect of backgrounds of different colours upon the colour of the hopper could be tested.

Frequent weighings of the hoppers were made at all stages of development, and these weighings were correlated with instar, sex, and the humidity obtaining during development. No one individual was followed through the whole of its development, and the weighings were taken at all periods of the respective stadia, so that the average figures represent the weights attained at the middle of each stadium.

For the determination of relative humidity the simple paper hygrometer manufactured by Messrs. Gallenkamp, and known as the Edney Paper Hygrometer, was used. It was found that, used with special precautions, this instrument gave very satisfactory results, accurate to within 1-2 per cent. R.H. It was found essential for accurate results that no one hygrometer should be used over a range greater than about 20 per cent. R.H. Separate hygrometers were therefore used for different ranges, and were never left in an atmosphere outside their respective ranges. Each hygrometer was calibrated for the range over which it was intended to be used. A series of ten sulphuric acid solutions were made up to give ten different relative humidities between 0 per cent. and 100 per cent., according to the tables of Wilson. These were kept in screw-top bottles, and their strength checked from time to time. It was found that the change in strength of even the strongest solutions in the course of about two months corresponded to a change in the relative humidity of the atmosphere over them of only 1–2 per cent., and this in spite of frequent opening of the bottles. Each bottle was provided inside with a glass stand upon which the hygrometer could be hung above the surface of the acid solution, which occupied about an inch in the bottom of the bottle. By taking readings over each humidity in its range, each hygrometer could be calibrated. At medium humidities little regulation of the instrument was required, but at low humidities, and sometimes at high humidities, it was necessary to adjust the needle, and to plot a curve relating the hygrometer reading to the actual relative humidity of the atmosphere. When not in use, each hygrometer was kept over a particular acid solution giving a relative humidity in the middle of its range. If a hygrometer was left for any length of time in a relative humidity considerably outside its normal range, it became inaccurate, and had to be recalibrated.

Hygrometers calibrated in this way can be left for long periods in an atmosphere whose relative humidity is fluctuating within their range, and will give readings accurate to within 1–2 per cent. R.H.

2. Rate of Growth.

Bodenheimer (1932) has summarised the most important work on growth in insects and discussed it from the point of view of the theory of a universal progression factor of 2. He has also provided what is to my knowledge the only detailed work on growth in locusts (Bodenheimer and others, 1930, on *Schistocerca*). More recently, Hodge (1933) has provided figures for the growth of *Melanoplus* on various diets.

(*a*) *Insects kept at high relative humidity.*

In Table I are presented the average weights of each instar, kept at saturation, and the average length of each stadium under these conditions. The figure for the weight of the adult insect is only very approximate, owing to the small number of

TABLE I.

Growth in Hoppers kept at high Humidity.

Instar	No. of weighings	Average weight in gm. ♂	Average weight in gm. ♀	Average	Percentage diff. between sexes	Growth quotient	No. of obs.	Length of stage days	P.E.
1st	21	—	—	0·021	—	—	20	6·8	±1·23
2nd	21	—	—	0·047	—	2·24	25	6·4	±1·11
3rd	20	0·089	0·142	0·116	59·5	2·47	24	5·9	±0·80
4th	22	0·205	0·368	0·287	79·5	2·47	18	7·4	±0·85
5th	21	0·675	0·998	0·837	47·9	2·92	11	11·5	±1·78
A	5	1·302	1·948	1·625	49·6	—	—	—	—

weighings and the fact that most of these refer to very recently mature adults. It will be seen that the progression factor is considerably in excess of 2 in all cases, nor has it been found possible, by the assumption of a latent instar in any position, to make the observations conform to the theory of a progression factor of 2 with any exactitude. It would be a mistake, in view of the way in which the figures have been obtained, to press this point too strongly, but as far as they go, the figures for *Locusta* are in agreement with those obtained by Hodge for *Melanoplus* in showing no accurate doubling of the weight from instar to instar.

TABLE II.

Rate of Growth of Hoppers kept at high Humidity.

Stage	A Weight increase gms.	B Length of stage, days	A/B Rate of growth, gms./day	C Av. wt. in stage, gms.	$\frac{100\ A/B}{C}$ % rate of growth
1st–2nd	0·026	6·6	0·0039	0·034	11·6
2nd–3rd	0·069	6·2	0·0112	0·083	13·5
3rd–4th	0·171	6·7	0·0257	0·202	12·7
4th–5th	0·550	9·5	0·0582	0·562	10·4

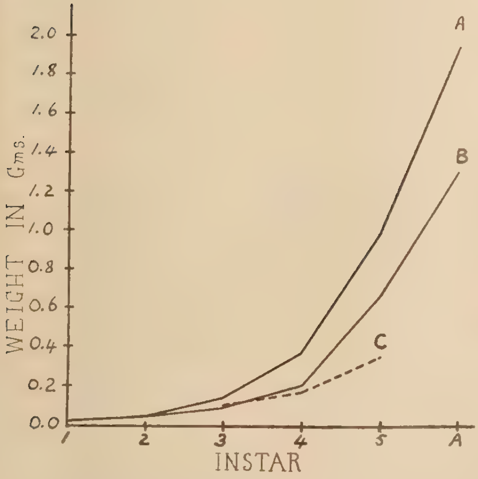

Fig. 1. Average weight in each instar of hoppers kept at high humidity (A and B) and at low humidity (C) : A, females ; B, males ; C, average figures for both sexes.

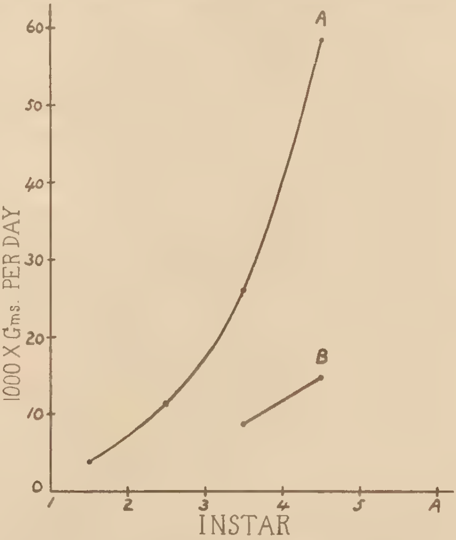

Fig. 2. Rate of increase in weight (1,000 × gms./day) between the mid-points of successive instars of hoppers kept at high humidity (A), and at low humidity (B).

As the Table and fig. 1 show, the sexes can be distinguished in weight as early as the third instar. The females weigh about 60 per cent. more than the males in the third instar, 80 per cent. in the fourth, and 50 per cent. in the fifth and adult. It seems very probable from these figures that the sexes could be distinguished by weight also in the first and second instars, and even perhaps in the embryo.

The figures for the length of the stadia show that the first three stadia are of about equal length, falling off slightly to the third ; the fourth stadium is rather longer, and the fifth much longer, nearly double the length of the first three. This is in general agreement with the results of Hodge. The total nymphal period is 38 days.

The figures given as the average weights of the instars represent the weights that would be reached about half-way through the stadium. The differences between the average weights of the instars therefore represent the amount of growth which takes place as the insect passes from the mid-point of one instar to the mid-point of the next. These weight increases are given in Table II in column A. Column B gives the length of time between these mid-points, calculated by taking in each case the mean of the lengths of the two stadia involved. These two sets of figures enable us to calculate the rate of growth, A/B, in gms/day, for the period between the mid-points of successive stadia. The figures in Column C are the average weights between the mid-points of successive stadia, calculated in the same way as the average periods between the mid-points in column B, and they enable us to express the rate of growth as a percentage of the average weight during the period for which the rate was calculated (100 A/B/C). These percentage rates are given in the next column.

TABLE III.

Growth of Hoppers kept at low Humidity.

Instar	No. of weighings	Av. wts., gms.	Growth quotient	% of wet, weights	Length of stage, days	No. of obs.	% of wet, days
2nd	—	—	—	—	12·0	2	182·4
3rd	11	0·096	—	82·8	8·6	7	145·8
4th	15	0·178	1·85	48·4	9·7	6	131·1
5th	14	0·357	2·06	42·6	14·5	4	126·1

TABLE IV.

Rate of Growth of Hoppers kept at low Humidity.

Stage	A Weight increase, gms.	B Length of stage, days	A/B Rate of growth, gms./day	C Av. wt. in stage, gms.	$\frac{100\ A/B}{C}$ % rate of growth
3rd–4th	0·082	9·2	0·0089	0·137	6·5
4th–5th	0·179	12·1	0·0148	0·268	5·5

The rate of growth, in gms./day, is plotted in fig. 2, the ordinates being expressed as 1,000 × gms./day. The curve rises very steeply with advancing development. In fig. 3, 1,000 times rate of growth in gms./day is plotted against 100 times the corresponding weights given in column C of Table II. The first three points lie almost exactly on a straight line, the fourth being slightly lower ; however, a straight line can be drawn to which all the points lie very close. Fig. 3 and the figures for the percentage rate of growth in Table II show that this rate is the same for stages of development between the first and fifth instars ; or perhaps the lower value for the period between the fourth and fifth signifies the beginning of the decline in the growth rate which must, sooner or later, take place.

(*b*) *Insects kept at low relative humidity.*

In the case of insects kept dry, data are available only for instars 3–5, and the numbers are smaller. The results are presented in Tables III and IV, corresponding to Tables I and II respectively. The weights of these hoppers kept dry are very considerably lower than those of hoppers kept wet. In the fifth column of Table III, the weights of each instar kept dry are expressed as a percentage of the corresponding weights of hoppers kept wet. The third instar hoppers were placed in dry conditions at the earliest in the second instar, and thus in their case the dry conditions had not had long in which to make their influence felt ; none the less the average weight in the third is only 82 per cent. of the weight of hoppers kept wet. In the fourth and fifth instars the percentage is only 40–50. These weights are plotted, together with those referring to hoppers kept wet, in fig. 1. The progression factor can be judged from only two figures, of which the one is exactly 2, the other slightly below 2.

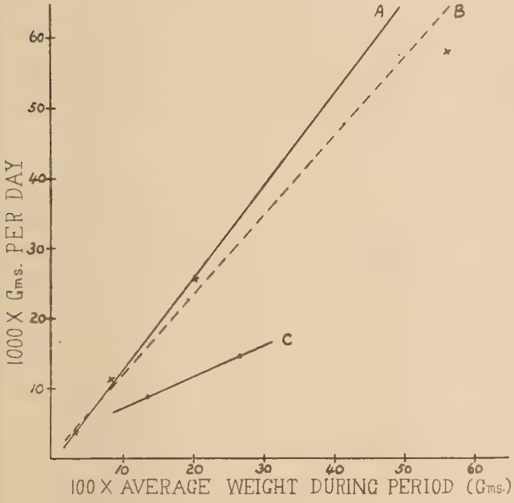

Fig. 3. Rate of increase in weight from instar to instar (1,000 × gms./day) plotted against 100 times the average weight during the period for which the rate was calculated : A and B, alternative lines to represent the relationship for hoppers kept at high humidity ; C, the relationship for hoppers kept at low humidity.

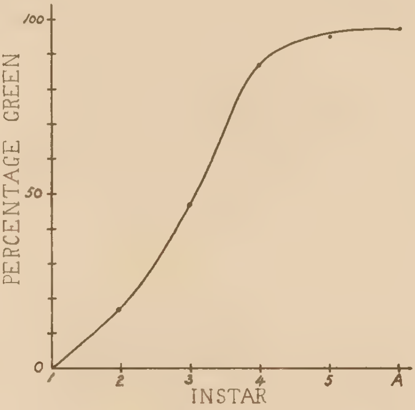

Fig. 4. Development of green coloration in *Locusta* ; percentage of individuals which were green in each instar.

The effect of dry conditions shows itself also in the length of each stadium, which is longer for each instar than for the corresponding instar kept wet. In the last column of Table III the length of each stadium is expressed as a percentage of the corresponding length in Table I. The increase in length of stadium is highest in the second instar ; life under these very dry conditions is normally impossible for second instar hoppers, so that it was to be expected that the difference would be greatest in that instar. In the later instars the difference progressively diminishes. It should be noted that the ratio of surface to weight is greatest in the smaller hoppers, and least in the larger, and it is this ratio which determines the rate of water loss, if we assume that the cuticle is equally permeable in all instars. If we allow a hypothetical length of 12 days for the first instar under these conditions, *i.e.*, the same length as the second, we can put the total nymphal period at 56·8 days, as compared with 38·0 days under wet conditions. Zolotarevsky (1933) found a similar lengthening of the nymphal period under dry conditions, and Hamilton finds that there is an optimum humidity of about 70 per cent, in which the nymphal period is shortest. At humidities higher and lower the period is lengthened.

Table IV gives the growth rates calculated in the same way as in Table II, and the results are also plotted in figs. 2 and 3. The rate is seen to be much lower than in hoppers kept wet ; the percentage rates, at 6·5 for the period 3rd–4th, and 5·5 for the period 4th–5th, are just half those of hoppers kept wet, and in this case also the 4th–5th period had a slightly slower rate than the 3rd–4th.

3. Coloration.

The work of Faure (1932) has established that there are three different types of pigmentation in *Locusta* and *Locustana*. The coloration of the hoppers of phase *gregaria* was due to excessive muscular activity, and was given the name *hypermetabolic* coloration ; it could only be developed in crowds, and was the only type of coloration possible for hoppers in dense crowds. Hoppers kept in isolation developed a green colour in a large proportion of cases if they were kept in a moist atmosphere with plenty of green food. This was the *nutritional* coloration. If isolated hoppers were kept dry, their coloration was determined by that of the background, and this type of coloration Faure termed *imitative*. A good resemblance was obtained to a number of colours, but green could not be developed in this way.

(*a*) *Hoppers kept at saturation.*

Table V and fig. 4 show the percentage of hoppers kept at saturation which were green in each instar. First instar hoppers are never green under any conditions : their colour is buff, grey, or nearly black, and is determined before hatching, one factor of importance being, according to Faure, the density of the parental population.

TABLE V.

Insects kept at Saturation.

Instar	No. green	% green	No. non-green	% non-green
1	0	0·0	38	100·0
2	6	16·7	30	83·3
3	13	46·4	15	53·6
4	20	87·0	3	13·0
5	20	95·2	1	4·8

Insects kept dry.

All such insects were non-green.

	3rd.	4th.	5th.	6th.
Numbers :	9	8	6	2

Second instar hoppers are usually buff or grey-buff, but a small percentage of green ones occurred. Of third instar hoppers kept under these conditions, nearly 50 per cent. were green, of fourth instars about 85 per cent., while in the fifth instar and the adult non-green hoppers were hardly ever found.

These results show that the development of the green colour may take some time, and that individuals differ in the speed with which they develop it. It should be noted that in all cases the other condition which Faure found essential to the development of the nutritional pigmentation, *viz.*, the presence of a constant supply of fresh green food, was fulfilled.

Black, white and green backgrounds were used with some of the hoppers kept wet. The only sign of any imitation of the colour of the background was in the case of the black background, on which some of the insects developed a very slight suffusion of tiny black spots overlying the green. This was only just noticeable, and the hopper would still be described without any hesitation as a green hopper. In other hoppers on the black background no difference whatever could be observed.

(*b*) *Hoppers kept dry.*

None of the 25 hoppers kept dry showed any sign of green coloration. When the special backgrounds were used, a definite resemblance to the white and black backgrounds was always developed after one or two moults, and in some cases, both on white and black, the resemblance was as remarkable as in the cases illustrated by Faure. Green was not developed against a green background, but the insects developed a grey-brown coloration.

It seems hardly necessary to add, in view of the exhaustive experiments of Faure, that the hypermetabolic coloration characteristic of *gregaria* hoppers was never developed in the hoppers kept in isolation.

The above results confirm those of Faure in every respect. They are interesting in view of the constancy of the conditions, and the accuracy with which they were known. In view of this constancy, the considerable individual variations in the time required for the development of the green colour in a saturated atmosphere are noteworthy.

4. The Abnormal Six-Instar Life-Cycle.

The usual number of instars in *Locusta* is five in both sexes (Uvarov, 1928), but sometimes six instars are found. Uvarov quotes Nikolsky as having observed a sixth instar in one female. Zolotarevsky (1933), working on *Locusta migratoria capito*, Sauss., found that there were always six instars in the female, and usually six in the male, but sometimes the males had five instars. Similar observations regarding the variability of the number of instars have been made on other ACRIDIDAE, and no satisfactory explanation of this phenomenon has been offered, in spite of the recent increases in our knowledge of the physiology of moulting.

Two previously unknown facts bearing upon the problem came to light in the course of the present experiments.

(*a*) The sixth instar appeared in all the females hatching from two particular egg-batches, and appeared irrespective of the humidity at which the hoppers had been kept. All the males from these two egg-batches had only five instars. Hoppers from all the other egg-batches had five instars in both sexes. Since all the hoppers were kept under identical conditions except in regard to relative humidity, and since there was no correlation between the occurrence of a sixth instar and relative humidity, the conclusion is justified that the propensity to show a sixth instar is an inherited one. This is in agreement with the results of Hodge on *Melanoplus*. He found that one or even two extra instars might occur in this Acridid, and that their occurrence was not in any way correlated with diet, which was varied in his experiments, while all other conditions were the same for all the insects used. Hodge, however, found no correlation of the extra instar with sex.

(*b*) The second point of interest is that the extra instar represented, even in hoppers from the same egg-batch, sometimes an extra third instar, and sometimes an extra fourth instar, in respect to the condition of the wing-rudiments. These two instars are readily separated, in the normal 5-instar cycle, by the fact that in the third instar the wing-rudiments are lateral, sloping obliquely backwards and downwards, while in the fourth they are dorsal, sloping obliquely backwards and upwards. The fifth instar shows a considerable elongation of the wing-rudiments as compared with the fourth. In the hoppers with a sixth instar, the fourth instar sometimes had the wing-rudiments lateral, in which case the fifth resembled the normal fourth, and the sixth the normal fifth ; or the fourth had the wings in the normal dorsal position, in which case the fifth showed no change, the wings remaining in the normal fourth condition, and only elongating to the normal fifth condition in the sixth instar. Zolotarevsky found that in his 6-instar insects the extra instar always represented an extra third, *i.e.*, had the wings lateral and pointing downwards.

5. Summary and Conclusions.

1. All material was reared under constant conditions of temperature, light intensity and relative humidity. Two relative humidities were used—very wet and very dry. In some cases various coloured backgrounds were used. All material was *solitaria*, and was kept isolated.

2. Average weights were calculated from weighings made at all periods within the stadia, and thus represent the weights at the mid-points of the stadia.

3. The figures could not be fitted to the theory of a progression factor of 2.

4. Females are on the average 50 per cent. heavier than males even in the third instar ; the sexes can probably be distinguished in this way much earlier.

5. The first three stadia are of about the same length ; the fourth is longer, the fifth much longer.

6. The percentage rate of growth between the mid-points of successive stadia is of the same order for all pairs, though somewhat lower for the first and last pairs.

7. Hoppers kept in a very dry atmosphere are much lighter than those kept wet —proportionally more so in the later than in the earlier instars ; on the other hand each stadium is lengthened—proportionally more so in the earlier than in the later stadia ; the percentage rate of growth is just half that of hoppers kept wet.

8. The findings of Faure in regard to the causes of differences in coloration were fully confirmed.

9. The occurrence of a sixth instar in the females is due to an inherited factor.

10. This " extra " instar may represent an extra morphological third instar or an extra morphological fourth instar.

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References.

Bodenheimer, F. S. (1930). Studien zur Epidemiologie, Oekologie und Physiologie der afrikanischen Wanderheuschrecken.—Z. angew. Ent. **15,** pp. 435–557, 55 figs.

—— (1932). Ueber Regelmässigkeiten im Wachstum der Insekten. (ii). Das Gewichtswachstum.—Arch. EntwickMech. **126,** pp. 554–574.

FAURE, J. C. (1932). The Phases of Locusts in South Africa.—Bull. Ent. Res. **23,** pp. 293–405.

HAMILTON, A. G. (1936). The relation of humidity and temperature to the development of three species of African locusts, *Locusta migratoria migratorioides*, R. & F., *Schistocerca gregaria*, Forsk., *Nomada septemfasciata*, Serv.—Trans. R. Ent. Soc. London **85** p. 1,

HODGE, C. (1933). Growth and nutrition of *Melanoplus differentialis*, Thomas. I. Growth on a satisfactory mixed diet and on diets of single food plants.—Physiol. Zool. **6,** pp. 306–328.

NIKOLSKY, V. V. (1925). The Asiatic Locust. Leningrad. 330 pp.

UVAROV, B. P. (1928.) Locusts and Grasshoppers. London. 352 pp.

WILSON, R. E. (1921). Industr. & Engng. Chem. **13,** p. 326.

ZOLOTAREVSKY, B. N. (1933). Contribution à l'étude biologique du Criquet migrateur (*Locusta migratoria capito*, Sauss.) dans ses foyers permanents.—Ann. Epiphyt. **19,** pp. 47–142.

PHASE VARIATION AND RATE OF DEVELOPMENT IN THE ALGERIAN RACE OF THE MIGRATORY LOCUST (*LOCUSTA MIGRATORIA*, L.).

By B. P. Uvarov, D.Sc., and A. G. Hamilton, B.Sc., B.Agr., Ph.D., D.I.C.,

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Introductory.

In view of the extensive experimental work on the African Migratory Locust (*Locusta migratoria migratorioides*, R. & F.) carried out in the locust laboratory of the Imperial Institute of Entomology, it appeared of considerable interest to arrange for some parallel experiments with a stock of the same species, but of another geographical race. From the point of view of phase variation, we were particularly anxious to work with material from a country where the species is not known in any but the solitary phase. Such a country is Algeria, where *L. migratoria*, L., is a not uncommon insect, but always occurring in the purest solitary phase, while it can be positively stated that swarms of the gregarious phase have definitely never occurred there in historical times. The initial stock was received through the kindness of Professor R. Pasquier, and we are most grateful to him for this valuable assistance.

The experimental locusts are bred in cages of the type described in another paper (Hamilton, 1936).

Phase Variation.

The original adults received from Algeria (F_1 in Table I) were most typical ph. *solitaria* in their coloration and in the measurements. Those of the F_2 hoppers which had been kept almost in isolation (only four hoppers in a large cage) produced adults which remained in the same phase. Hoppers of the same generation but bred in a crowded cage (69 hoppers to a cage) very soon assumed the coloration of the ph. *transiens* and the resulting adults, as can be seen from the table, were quite near ph. *gregaria*. Their characters were practically retained in the next two generations, F_3 and F_4. The eggs of the fourth generation were badly damaged by mites, so that the generation F_5 had to be omitted from the table. In the F_6 generation, however, the ph. *transiens* characters were well maintained, while in the F_7 most of the ratios approached very closely those typical of the ph. *gregaria*.

These results show that a stock of *Locusta migratoria* ph. *solitaria* from a country where no ph. *gregaria* had been produced, or present, within historical times, can give rise to that phase just as easily as in the case of a stock derived from a country where the transformation occurs naturally. Similar results have already been obtained by Faure (1932) with the stock from Transvaal, which is visited by swarms of the ph. *gregaria* only very exceptionally, but our case is still more convincing since no swarms have ever been known to occur in Algeria.

It will be seen from the table that no complete transformation into a typical ph. *gregaria* has been obtained, but it was also a conclusion of Faure (1932) that the rate of activity in cage experiments is never as high as in the field, so that a full transformation cannot be expected. This is confirmed by the figures given in Table I for subsp. *migratorioides*, bred from a stock of the typical ph. *gregaria* in sufficiently crowded conditions, but nevertheless not attaining the values of ratios characteristic of the typical ph. *gregaria* of that race.

TABLE I.

Phase Variation in the Algerian Race and Subsp. migratorioides.

Race	No. of generation	Temperature °F.	Relative humidity %	No. of hoppers in cage	Sex	Measurements of adults									
						E	F	E/F	P	M	H	C	P/C	H/C	M/C
ALGERIAN	F₁	—	—	—	♂♂	3·96	2·25	1·76	0·85	0·59	0·80	0·62	1·37	1·30	0·95
					♀♀	4·90	2·80	1·75	1·05	0·75	1·05	0·73	1·44	1·44	1·03
	F₂	90	65	4	♂♂	3·60	2·20	1·64	0·75	0·55	0·70	0·55	1·36	1·27	1·00
					♀♀	4·55	2·50	1·82	1·00	0·73	0·95	0·75	1·33	1·27	0·99
	F₂	100	60	69	♂♂	3·97	2·08	1·91	0·77	0·58	0·75	0·61	1·26	1·23	0·95
					♀♀	4·43	2·28	1·94	0·82	0·60	0·83	0·68	1·21	1·22	0·88
	F₃	90	60	63	♂♂	4·18	2·18	1·92	0·73	0·57	0·73	0·64	1·14	1·14	0·89
					♀♀	4·61	2·48	1·86	0·88	0·66	0·87	0·75	1·17	1·16	0·88
	F₄	100/80	55/85	84	♂♂	3·96	2·17	1·83	0·77	0·56	0·74	0·63	1·22	1·17	0·89
					♀♀	4·61	2·48	1·86	0·88	0·65	0·87	0·73	1·21	1·19	0·89
	F₅	—	—	—		—	—	—	—	—	—	—	—	—	—
	F₆	90	70	41	♂♂	4·01	2·16	1·86	0·74	0·60	0·73	0·64	1·16	1·16	0·94
					♀♀	4·37	2·33	1·87	0·86	0·69	0·85	0·75	1·15	1·13	0·92
	F₇	80	75	38	♂♂	4·07	2·12	1·92	0·80	0·60	0·74	0·66	1·21	1·12	0·91
					♀♀	4·71	2·43	1·94	0·91	0·71	0·87	0·77	1·18	1·13	0·91
migratorioides		90	70	60	♂♂	4·20	2·16	1·94	0·82	0·59	0·81	0·68	1·21	1·19	0·87
					♀♀	4·68	2·29	2·04	0·84	0·68	0·89	0·76	1·11	1·17	0·89
		80	75	105	♂♂	4·17	2·05	2·02	0·76	0·56	0·72	0·67	1·13	1·08	0·84
					♀♀	4·58	2·24	2·02	0·84	0·63	0·82	0·73	1·15	1·12	0·86

Note.—E, length of elytron ; F, length of femur ; P, length of pronotum ; M, width of pronotum at the constriction ; H, height of pronotum ; C, maximum width of head.

Race Characters.

It would be of great theoretical interest to obtain definite evidence as to whether the Algerian individuals can be referred to the subsp. *migratorioides* which occurs in the tropical parts of Africa, or are more closely related to the subsp. *migratoria* of the south-eastern Palaearctic region. Since no reliable characters are as yet known by which these two races can be separated in the solitary phase, it was hoped that the bred specimens of the ph. *gregaria* might provide the necessary data. However, the measurements and their ratios in the case of individuals most widely distinct from the ph. *solitaria* can be interpreted in two ways. First, the fact that Algerian individuals bred in crowded conditions did not reach the same ratios as in the case of subsp. *migratorioides* bred under similar conditions, may be taken to indicate a racial difference. Indeed, the ratios of such individuals are closer to those which are considered typical of the subsp. *migratoria* than to the ratios of subsp. *migratorioides*. On the other hand, it may be suggested that the rate of transformation into the ph. *gregaria*, in the case of Algerian stock, with its numberless previous generations of the ph. *solitaria*, may be conceivably slower than with the *migratorioides* stock actually started from the ph. *gregaria*.

The question of the racial affinity of the Algerian stock cannot, therefore, be settled at present, when we do not know yet whether the limit of its transformation into ph. *gregaria* has been reached. Further experiments with locusts bred under extreme crowded conditions may produce more definite results. In the meantime, the Algerian race can be considered as probably more closely allied to the Palaearctic subsp. *migratoria* than to the tropical African subsp. *migratorioides.*

Rate of Development.

Considering that the Algerian race of *Locusta* lives in a climate substantially different from that to which the tropical subspecies is subjected, it was not unnatural to expect that their respective reactions to identical environmental conditions might be different.

Table II summarises experimental data on the rate of development of the Algerian race at different combinations of temperature and humidity. For comparison, the data on the development of subsp. *migratorioides* under the same conditions are given.

TABLE II.

Rate of Development of the Algerian Race and Subsp. migratorioides *at different Temperatures and Humidities.*

Temperature °F.	Relative humidity %	Algerian Race					migratorioides			
		Generation bred in laboratory	Average length of hopper development (days)		Age of adults when 1st egg-pod deposited (days)	Embryonic development (days)	Average length of hopper development (days)		Age of adults when 1st egg-pod deposited (days)	Embryonic development (days)
			♂♂	♀♀			♂♂	♀♀		
90	65	F_2	24·0	35·0	38	12·0	27·5	28·2	20	11·3
90	70	F_2			30					
90	70	F_3			28	13·6				
90	70	F_5	25·2	27·7	39	12·0	27·3	28·3	21	12·3
90	70	F_6	21·2	24·1	24					
90	60	F_3	26·4	28·8	63	13·5	27·7	30·5	25	11·0
90	60	F_5	27·2	31·4	55	12·0				
100	60	F_2	23·0	25·0	25		22·0	26·6	15	12·7
$\frac{100}{80}$	$\frac{55}{85}$	F_4	25·6	27·3	26	14·0	30·0	31·9	21	13·5

The table shows that there is no significant difference in the rate of hopper or embryonic development of the two races. An important difference occurs, however, in the rate of sexual maturation, expressed as the number of days between the emergence of adults and the laying of the first egg-pod. At 90°F. and 60 per cent. relative humidity the Algerian race required from 55 to 63 days to mature, while the tropical race matured under the same conditions in 25 days. At 90°F. and 65 per cent. relative humidity the figures are 38 and 20 days respectively. With a further rise in the humidity to 70 per cent. at the same temperature, there was still a considerable difference, though in one experiment, with the F_6 generation of the Algerian race, it amounted only to three days. At 100°F. and 60 per cent. relative humidity the rate of development generally increased in both races, but adults of the Algerian race matured in 25 days, as against 15 in the case of the subsp. *migratorioides*. In the last experiment shown in the table, when the temperature was kept at 100°F. during the day and 80°F. at night and the relative humidity fluctuated between 55 and 85 per cent. respectively, the difference between the two races was very small. This may be due to the inexactitude of this experiment as regards the relative humidity, which appears to be a very important factor affecting the rate of sexual maturation. Discarding this experiment, we have to conclude that the rate of sexual maturation in the Algerian race is considerably slower than in the tropical race, sometimes twice as slow and even less, when bred under identical conditions. Since the difference tends to become less at higher humidities, it may be suggested that the humidity requirements of the Algerian race in connection with sexual maturation are higher than in the tropical race. In any case a significant physiological difference exists between the two races.

Summary.

1. The Algerian race of *Locusta migratoria*, L., although never known to occur in the gregarious phase in nature can be transformed into almost typical ph. *gregaria* by breeding in crowded cages.

2. Biometric characters of such individuals indicate a relationship of the Algerian race to the subsp. *migratoria*, but the data are insufficient for a final decision on this point.

3. The rate of embryonic and hopper development in the Algerian race is the same as in the tropical African subsp. *migratorioides* when bred at the same temperature and relative humidity.

4. The rate of sexual maturation is very much slower in the Algerian race than in the tropical one bred under the same conditions.

References.

FAURE, J. C. (1932). The phases of locusts in South Africa.—Bull. Ent. Res. **23,** pp. 293–424, 25 pls., 1 map.

HAMILTON, A. G. (1936). The relation of humidity and temperature to the development of three species of African locusts.—Trans. R. Ent. Soc. London, **85,** p. 1.

THE ORIENTAL MIGRATORY LOCUST (*LOCUSTA MIGRATORIA MANILENSIS*, MEYEN 1835).

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Introductory.

The form of the Migratory Locust (*Locusta migratoria*, L.) appearing in swarms in south-eastern tropical Asia, the Malay Archipelago and the Philippine Islands, is usually referred to the subspecies *migratorioides* (Reiche & Fairmaire) which occurs in tropical Africa. However, even a superficial examination of series of specimens of the gregarious phase is sufficient to show that the Oriental locusts are somewhat different in their size and structure from the African ones. It was, therefore, of interest to compare the two forms biometrically and the results as described below have proved that the Oriental Migratory Locust should be regarded as a subspecies distinct from the African one, as well as from the three other subspecies of *Locusta migratoria* so far distinguished (Uvarov & Zolotarevsky, 1929).

Nomenclature.

It appears convenient, before discussing the characters of the Oriental Locust, to decide on the name which should be applied to it.

So far as it has been possible to ascertain, the earliest description referring to this locust was that given by Meyen (1835) in the account of his voyage published exactly a hundred years ago. Arriving at Manila, Philippine Islands, he saw large swarms of locusts and was told that they were devastating the whole island of Luzon. His description of the insects is worth quoting in full, since the book is not easily obtainable :—

" Das Thier bildet eine neue Art der Gattung *Acrydium* Latr., die wir *Acrydium manilense* nennen ; es ist 2 Zoll lang und von brauner Farbe, die Flügel sind etwas kürzer als der Hinterleib. Die oberen Flügeldecken sind schwarz gefleckt und ihre Adern sind niedlich schwarz gefärbt ; die unteren Flügel sind bräunlich, ungefleckt und sehr gross. Der Halsschild hat einen kleinen Kamm. Das Männchen ist etwas grösser als das Weibchen und ganz braunrot gefärbt, der Bauch des Weibchens ist schwefelgelb und das Brustschild heller als bei dem Männchen."

The above description is not very lucid, and the author has obviously confused the two sexes, the male of *Locusta* being smaller and more brightly coloured than the female when sexually mature. However, the description leaves no doubt that the locust observed by Meyen was the same which now occurs in swarms in the Philippine Islands.

The same locust was described again by Brunner von Wattenwyl in 1862 under the name *Pachytylus obtusus* from specimens obtained in Manila in a swarm mixed with " *Pachytylus migratorius*." Judging from the description and from the type, kindly sent by Dr. Max Beier, the name *obtusus* was applied by Brunner to individuals of the gregarious phase, while those of the ph. *transiens* have been referred by him to " *migratorius*." Both names, *obtusus* and *manilensis* were overlooked by all subsequent authors, and I am greatly obliged to my friend Dr. C. Willemse for drawing my attention to Brunner's paper and to a travel book by Jagor (1875) where *manilensis* is mentioned, which enabled me to trace its original description by Meyen. More recent authors referred to the Oriental Locust under the names *migratorioides* or *migratoria*, probably according to the phase of the specimens examined, since its ph. *gregaria* resembles the first one, and the ph. *transiens* is more like the second.

The synonymy of the Oriental Locust would now appear, as follows :—

1835. *Acrydium manilense*, Meyen, Reise um die Erde etc., **2,** p. 197.

1862. *Pachytylus obtusus*, Brunner von Wattenwyl, Verh. zool.-bot. Ges. Wien, **12,** p. 94.

1875. *Oedipoda manilensis*, Jagor, Travels in the Philippines, p. 272, footnote.

The Oriental Migratory Locust is proposed here as the common name for *Locusta migratoria manilensis*, while it is also proposed that *Locusta migratoria migratorioides*, R. & F., should be called the African Migratory Locust, since the name Tropical Migratory Locust applied to it at present becomes now inexact.

Systematic Position.

The Oriental form of the Migratory Locust can be distinguished at once from the African subspecies *migratorioides* as a smaller insect, with a less constricted pronotum and a more narrow head in the gregarious phase. These differences are made quite obvious when the standard measurements and ratios of the two forms are compared (see Table I).

TABLE I.

Average Measurements and Ratios of the ph. gregaria *in different Subspecies of* Locusta migratoria.

Subspecies	Males						Females					
	E	F	E/F	P/C	H/C	M/C	E	F	E/F	P/C	H/C	M/C
rossica	3·8	1·9	2·0	1·30	1·22	0·88	4·1	2·3	1·78	1·14	1·21	0·86
migratoria	5·1	2·4	2·13	1·10	1·16	0·85	5·35	2·5	2·11	1·17	1·16	0·87
manilensis	4·26	2·08	2·11	1·11	1·10	0·81	4·58	2·13	2·16	1·11	1·08	0·83
migratorioides ...	4·71	2·18	2·17	0·99	1·06	0·75	4·98	2·25	2·22	0·94	1·07	0·74
capito	4·64	2·22	2·09	1·04	1·07	0·72	4·83	2·27	2·13	1·00	1·11	0·72

Note.—E, length of elytron ; F, length of femur ; P, length of pronotum ; H, height of pronotum ; M, width of pronotum at the constriction ; C, maximum width of the head.

The table shows at a glance, that the Oriental Locust (*manilensis*) is more closely allied to the two Palaearctic subspecies *rossica* and *migratoria* than to the African *migratorioides* and the Madagascar *capito*. In its size, *manilensis* occupies an intermediate place between *rossica* and *migratoria*, being nearer to the former, since the smallest specimens of *manilensis* (see Table II) are actually smaller than the average *rossica*. The E/F ratio shows little difference according to subspecies, being essentially a phase character. On the other hand, very significant differences can be observed in the ratios expressing the structure of the pronotum and head. The P/C ratio, *i.e.*, the length of pronotum expressed in relation to the maximum width of the head, is very near in *manilensis* to that in the two Palaearctic subspecies and well distinct from the ratios obtained in *migratorioides* and *capito*. This difference in the ratios expresses the fact that the pronotum in *manilensis* (gregarious phase) is of the same type as in *migratoria* and *rossica*, *i.e.*, more elongated and less rounded behind, while it is very short and broadly rounded in *migratorioides* and *capito*. In the H/C ratio, on the other hand, *manilensis* is nearer to the two last named subspecies than to the Palaearctic ones. This is due to the fact that the pronotum in *manilensis* is slightly saddle-shaped, with the median keel subconcave in profile. The M/C ratio, however, again demonstrates that *manilensis* belongs to the group of *rossica* and *migratoria*,

TABLE II.—*Measurements and Ratios of L. m. manilensis from different Localities.*

Localities	E			F			E/F			P/C			H/C			M/C		
	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.
CHINA.																		
Nanking, 1933																		
ph. *gregaria*, males	3·92	4·68	4·30	1·89	2·41	2·15	1·41	2·11	1·99	0·94	1·28	1·14	0·92	1·27	1·11	0·72	0·96	0·83
,, females	3·97	5·18	4·57	1·90	2·46	1·18	1·87	2·22	2·11	0·95	1·23	1·09	0·95	1·15	1·08	0·71	0·96	0·82
Nanking, 1934																		
ph. *gregaria*, male	—	—	4·05	—	—	1·96	—	—	2·07	—	—	1·11	—	—	1·11	—	—	0·84
,, female	—	—	4·59	—	—	2·08	—	—	2·21	—	—	1·13	—	—	1·14	—	—	0·85
Nanking, 1933																		
ph. *transiens*, males	3·63	4·45	4·04	1·96	2·32	2·14	1·79	2·04	1·89	1·04	1·45	1·26	1·07	1·31	1·21	0·74	0·97	0·88
,, females	4·55	5·14	4·84	2·08	2·87	2·47	1·75	2·10	1·96	1·11	1·50	1·28	1·10	1·29	1·24	0·83	1·00	0·89
Nanking, 1932																		
ph. *solitaria*, male	—	—	4·20	—	—	2·25	—	—	1·87	—	—	1·33	—	—	1·25	—	—	0·91
,, female	—	—	4·60	—	—	2·40	—	—	1·92	—	—	1·53	—	—	1·31	—	—	0·92
INDO-CHINA.																		
Annam.																		
ph. *transiens*, males	3·78	3·83	3·80	2·01	2·09	2·05	1·80	1·90	1·85	1·14	1·21	1·17	1·14	1·21	1·17	0·82	0·89	0·85
,, females	—	—	4·60	—	—	2·40	—	—	1·92	—	—	1·32	—	—	1·23	—	—	0·88
MALAYA, 1930																		
ph. *transiens*, males	3·94	4·45	4·22	2·16	2·26	2·19	1·82	1·97	1·92	1·17	1·27	1·23	1·15	1·19	1·17	0·85	0·90	0·87
,, female	—	—	4·87	—	—	2·38	—	—	2·05	—	—	1·15	—	—	1·14	—	—	0·88
Bred in cages.																		
ph. *transiens*, males	3·56	4·46	4·01	1·84	2·40	2·12	1·69	2·02	1·83	1·14	1·28	1·21	1·08	1·22	1·14	0·77	0·90	0·84
,, females	4·05	4·90	4·47	2·37	2·80	2·58	1·69	1·90	1·80	1·12	1·31	1·20	1·09	1·23	1·15	0·82	0·90	0·85
BORNEO.																		
Sandakan, 1934.																		
ph. *transiens*, males	3·23	3·76	3·49	1·78	2·05	1·91	1·74	1·91	1·82	1·25	1·48	1·35	1·16	1·40	1·25	0·91	0·98	0·94
,, females	4·45	5·08	4·76	2·44	2·86	2·65	1·77	1·86	1·81	1·27	1·37	1·31	1·23	1·29	1·25	0·92	0·99	0·94
CELEBES.																		
Taroena, N. Celebes, 1932.																		
ph. *gregaria*, male	—	—	4·43	—	—	2·06	—	—	2·15	—	—	1·09	—	—	1·09	—	—	0·86
PHILIPPINES.																		
Los Banos, 1934, bred in cages.																		
ph. *transiens*, males	3·39	3·63	3·51	1·75	1·90	1·87	1·76	1·96	1·88	1·21	1·35	1·26	1·13	1·25	1·20	0·86	0·94	0·89
,, females	3·92	4·29	4·10	1·99	2·35	2·17	1·87	1·97	1·92	1·09	1·33	1·22	1·15	1·26	1·20	0·80	0·93	0·89
All ph. *gregaria*, males	3·92	4·68	4·26	1·89	2·41	2·08	1·41	2·15	2·11	0·94	1·28	1·11	0·92	1·27	1·10	0·72	0·96	0·81
,, ,, females	3·97	5·18	4·58	1·90	2·46	2·13	1·87	2·22	2·16	0·95	1·23	1·11	0·95	1·15	1·08	0·71	0·96	0·83
All ph. *transiens*, males	3·23	4·45	3·84	1·75	2·40	2·05	1·69	2·04	1·83	1·04	1·48	1·25	1·07	1·40	1·19	0·77	0·98	0·86
,, ,, females	3·92	5·14	4·61	1·99	2·87	2·44	1·69	2·10	1·91	1·09	1·50	1·25	1·09	1·29	1·20	0·83	1·00	0·88
ph. *solitaria*, male	—	—	4·20	—	—	2·25	—	—	1·87	—	—	1·33	—	—	1·25	—	—	0·91
,, female	—	—	4·60	—	—	2·40	—	—	1·92	—	—	1·53	—	—	1·31	—	—	0·92

while *capito* and *migratorioides* form a very distinct and compact group characterised by a very strongly constricted pronotum (low value of M) and very broad head (high value of C).

There is no doubt, therefore, that the Oriental Locust should be regarded as a distinct subspecies of *Locusta migratoria*. The characteristics of this subspecies can be better seen from Table II where the maximum, minimum and average measurements of specimens from various localities and of the different phases are given.

The table shows, first of all, that the subspecies *manilensis* is sufficiently stable in its characters when specimens from several widely distant countries are studied. Unfortunately, my material from some of the countries was not sufficiently abundant to obtain reliable figures, and further biometrical work will be necessary to characterise the subspecies more exactly. This is particularly desirable with regard to the solitary phase, which has remained practically unstudied, while more abundant material of the typical gregarious phase would also provide more exact figures than I am able to present.

Invasion and Outbreak Areas.

While our data on the distribution of the Oriental Locust are admittedly very incomplete, some recent publications, as well as manuscript reports accumulated at the Imperial Institute of Entomology, permit me to discuss this question more fully than was possible in my work on locusts and grasshoppers (Uvarov, 1928).

China.

Our knowledge of the invasion and outbreak areas in China was extremely meagre until the publication of the results of recent investigations organised by the National Agricultural Research Bureau at Nanking (Woo & Cheng, 1934 ; Tsou, 1935). Unfortunately, the text of these valuable reports is in Chinese, and the summaries are much too brief and lacking in essential details. However, I was very fortunate in having the personal co-operation of Mr. We-i Yang who had been working in the main locust region of China for several years and who assisted me in preparing the map (fig. 1) of the breeding areas and in drawing up the general description. The map and the description were prepared before the paper by Tsou (1935) became available, but scarcely any alterations and only a few additions were necessitated by this paper.

The general region of the occurrence of locusts in China comprises the coastal and subcoastal areas beginning at the Gulf of Chihli in the north (39°N.) to Hangchow Bay (30°30′N.) in the south. Within that region subject to invasions, the more or less permanent breeding areas are restricted to the system of the lower Hwang-ho (Yellow River), more particularly to its old bed, which is now abandoned. The river flowed along that bed into the Yellow Sea until 1851, when it burst its banks and turned north-east into the Gulf of Chihli. The ancient delta lands within the Kiangsu province are now a maze of channels and lakes, with alluvial, mostly sandy, soils between them. These lands are largely cultivated, but some are not and these are overgrown with reeds. The old bed of the Hwang-ho is usually dry, but sometimes when the flood is high, the old bed becomes filled with water, which overflows its banks and forms more or less temporary lakes.

A very important breeding area (and probably an outbreak area) is situated round the lake Hungtze. This lake sometimes receives the flood-water from the River Hwai-ho, as well as from the old bed of the Hwang-ho, and its size varies greatly from year to year, as it has no outlet to the sea. Similar areas are found round the lakes Hoei-San (or Wei-shan) and Loma, though the latter is not indicated by Tsou as an important breeding area. These two lakes receive an overflow of water from the old bed of the Hwang-ho and also fluctuate in their size.

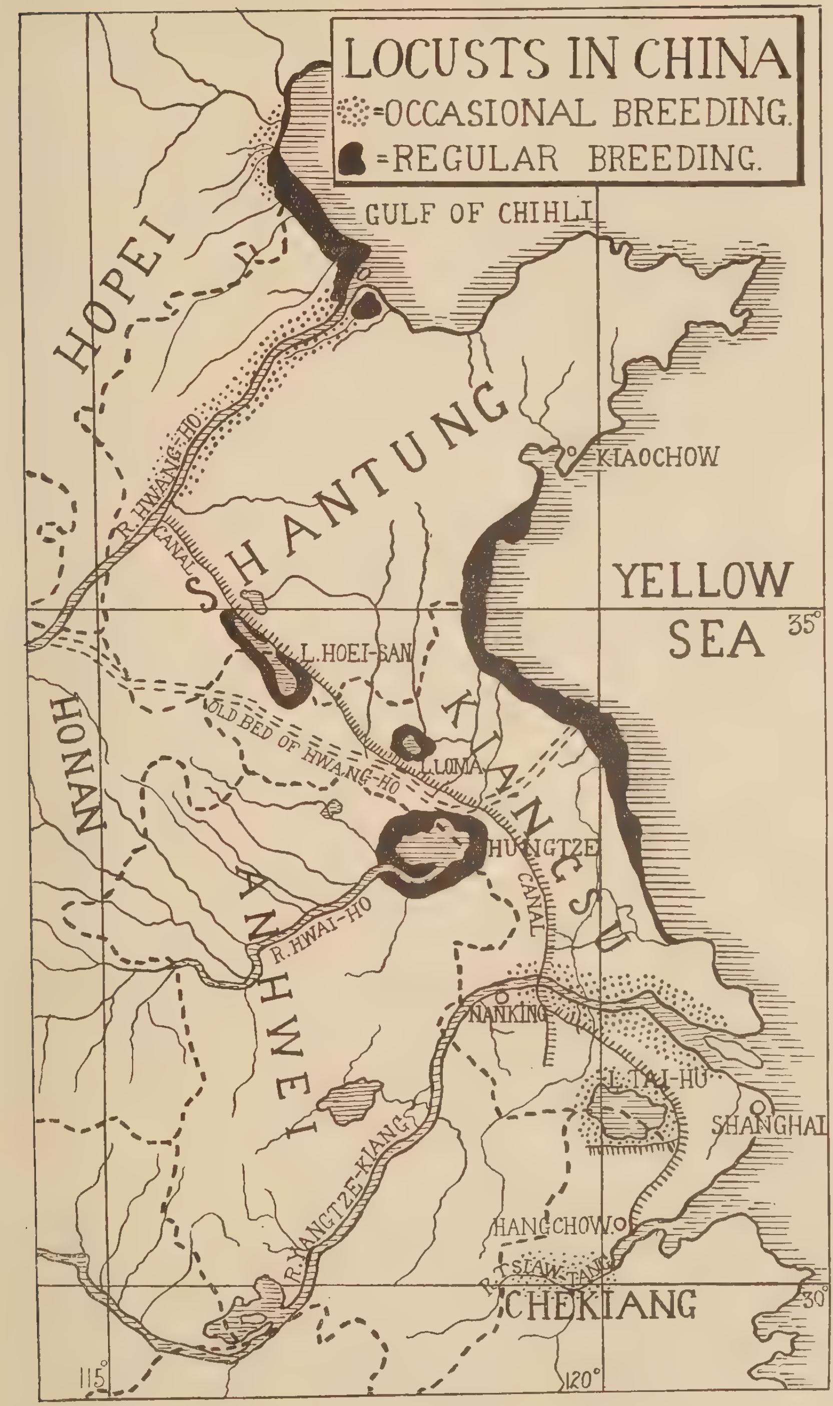
LOCUSTS IN CHINA
▨ = OCCASIONAL BREEDING.
● = REGULAR BREEDING.
GULF OF CHIHLI
HOPEI
SHANTUNG
KIAOCHOW
YELLOW SEA
35°
R. HWANG-HO
CANAL
L. HOEI-SAN
HONAN
OLD BED OF HWANG-HO
L. LOMA
KIANGSU
HUNGTZE
CANAL
ANHWEI
R. HWAI-HO
NANKING
L. TAI-HU
SHANGHAI
R. YANGTZE-KIANG
HANGCHOW
R. TSIAW-TANG
CHEKIANG
30°
115°
120°

Fig. 1.

The vegetation on the low sandy shores of the lake Hoei-San consists of *Phragmites communis*, *Polygonum*, *Panicum*, *Artemisia* and some Gramineae occupying a narrow zone between water and the cultivated land (Tsou, 1935).

Apart from the shores of the three lakes just mentioned, there are two important breeding areas on the sea-coast. One of them occupies a narrow zone along the coast of most of the Kiangsu province, extending into the southern part of the Shantung province. Farther north the coast is rocky, since the granite hills occupying the interior of the Shantung peninsula extend here to the sea. The littoral area of Kiangsu is sandy and its vegetation consists of a zone of *Tamarix* scrub nearest to the sea, followed by a zone with a sparse cover of *Calamagrostis pseudophragmites*, *Tragus racemosus*, *Apocynum venetum*, *Thesium chinense*, etc. This zone is most suitable for locust breeding and is followed by cultivated land. According to Mr. We-i Yang this coastal zone of Kiangsu is the most important locust breeding area, which of course does not necessarily mean an outbreak area.

Another coastal area described by Tsou (1935) is that on the shores of the Gulf of Chihli. According to that author, there are extensive areas of alkaline lands in the Hopei province which remain uncultivated. Their vegetation consists of *Tragus racemosus*, *Calamagrostis pseudophragmites*, *Tribulus terrestris*, *Thesium chinense*, *Statice sinensis* and *Tamarix chinensis*. His illustrations show that the vegetation cover is not dense, and that there is a great deal of bare soil between plants. To what extent such lands may function as outbreak areas remains unknown, but they must be very suitable for the breeding of swarms.

This brief outline of the main breeding areas in China is extremely interesting because they show an amazing resemblance to the outbreak areas of other subspecies of *Locusta migratoria*. Indeed, we have here, as elsewhere, a wide sandy river delta, with an ephemeral system of lakes and channels, so that wide stretches of land are submerged one year and dry the next. Thus, a habitat very unstable in its character and extent is obtained and this is typical for all known outbreak areas of *Locusta*. Moreover, the climate of the country is characterised by a dry, hot spring and early summer, with more abundant precipitation in the autumn. As a result, the conditions, at least in summer, tend to be of a dry subtropical type. We have here, therefore, dry, sandy plains with sparse vegetation subject to extensive flooding, in an otherwise semi-arid country. These conditions provide a striking analogy with other outbreak areas of *Locusta* in Central Asia and in West Africa.

As regards the actual outbreak areas in China, it must be remembered that the investigations by Chinese entomologists have so far been conducted only during the years of swarming. Therefore, the breeding areas located by them may not be the outbreak areas. Indeed, it appears almost certain that the original outbreak areas are much more restricted than the breeding areas, and I would suggest that the most suspicious places in this respect are the shores of the three lakes mentioned above, where great fluctuations of the water level occur. On the other hand, the presence of outbreak areas on the sea-coast appears more doubtful, as there are no sudden changes in that habitat.

Tsou (*loc. cit.*) attempted to analyse the climatic causes of outbreaks in China, but the problem is a very complicated one, since one must take into account not only the actual weather conditions on the spot, but also the level of flood-water in the Hwang-ho and its dependent lakes. This level naturally is regulated not by local rainfall, but by that in the mountains whence the river and its tributaries flow. The local weather conditions are, of course, also of importance, since on them depends the extent of breeding in a particular year. The origin of outbreaks must be, therefore, investigated by studying carefully (*a*) the weather conditions which affect breeding of the solitary phase; and (*b*) the changes in the habitat of the solitary phase caused by fluctuations in water-level. Stationary work on one of the lakes, with a quantitative study of the population of solitary locusts for a period of several years would certainly throw some light on the causes of outbreaks.

Borneo.

Until recently, our knowledge of locusts in Borneo was practically nil, but some careful observations communicated during the last few years by Mr. H. G. Keith, Director of Agriculture, North Borneo, supply us with most valuable data on the problem. The following notes are based entirely on Mr. Keith's reports which he has very generously permitted me to use.

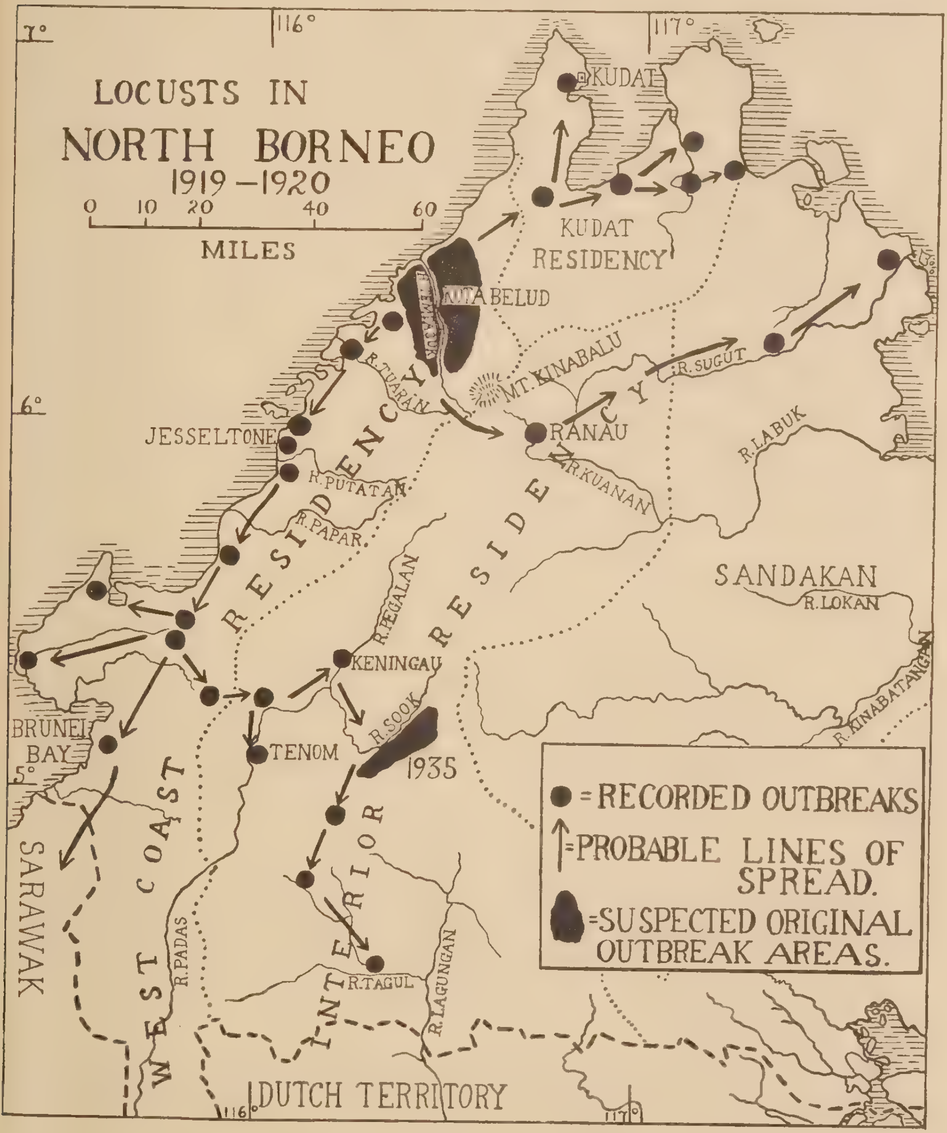
7°
116°
117°
LOCUSTS IN
NORTH BORNEO
1919 – 1920
0 10 20 40 60
MILES
KUDAT
KUDAT RESIDENCY
KOTA BELUD
R. TEMPASUK
R. TUARAN
MT. KINABALU
R. SUGUT
RANAU
R. KUANAN
R. LABUK
6°
JESSELTON
R. PUTATAN
R. PAPAR
WEST COAST RESIDENCY
INTERIOR RESIDENCY
SANDAKAN
R. LOKAN
R. PEGALAN
KENINGAU
R. SOOK
1935
TENOM
R. KINABATANGAN
BRUNEI BAY
5°
SARAWAK
R. PADAS
R. TAGUL
R. LAGUNGAN
DUTCH TERRITORY
116°
117°
● = RECORDED OUTBREAKS
↑ = PROBABLE LINES OF SPREAD.
= SUSPECTED ORIGINAL OUTBREAK AREAS.

Fig. 2.

No definite records are available of the presence of locust swarms in Borneo before 1918, but there are indications that they were known in the island earlier. In December 1918 an invasion commenced with a large swarm appearing in the Tempasuk district, in the north-west of British North Borneo (see fig. 2). Since then there was a steady spread of flying swarms and of hopper-infested areas throughout the year 1919 and the early part of 1920. The areas where most breeding took place were along the whole west coast of the British territory, from the Kudat peninsula down to the Sarawak boundary, which was crossed by some swarms in October 1919. The infestation spread into the interior as well, round Mt. Kinabalu to Ranau and along the River Sugut ; in the south some swarms penetrated to Tenom, Keningau, Sook and the River Tagul. In the same year some swarms flew to the island of Labuan, at the entrance to Brunei Bay (Gater, 1924). It is difficult to judge from the reports how many generations were produced during that period, but there was certainly more than one and there was obviously a considerable overlapping of generations. Towards the end of 1919 reports became somewhat less numerous, and in March 1920 the territory was considered practically clear. Scattered reports, however, continued to arrive during the second part of 1920. No locusts were reported in 1921, only one case of hoppers breeding was reported in each of the years 1922, 1923 and 1924, and none again in 1925. From May 1926 there was again an increase in the number of reported swarms and hopper-bands. The infestation gradually increased again, but was apparently less widely spread and restricted mainly to the more northern part of the west coast. By the end of 1927 the invasion was practically ended ; but in August 1927 locusts appeared again and continued in the same general area until November of the same year. After an interval lasting until May 1930 swarms were again active until the middle of 1931. After that no reports are available and presumably there was no trouble. In July 1933 three scattered swarms were reported from the Kota Belud district, in the north of the west coast. A small outbreak in the same district was observed in August 1934. In February 1935 another local outbreak occurred in the interior, on the Sook plain, while in July of the same year a serious outbreak was reported again in the Kota Belud district.

TABLE III.

Measurements of Material from two incipient Swarms in North Borneo.

	E			F			E/F			P/C	H/C	M/C
	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Av.	Av.	Av.
1934												
11♂♂	3·23	3·76	3·49	1·78	2·05	1·91	1·74	1·84	1·82	1·35	1·25	0·94
3♀♀	4·45	5·08	4·76	2·44	2·86	2·65	1·77	1·86	1·81	1·31	1·25	0·94
1935												
43♂♂	3·42	4·57	3·80	1·73	2·98	1·98	1·72	2·14	1·97	1·17	1·19	0·85
46♀♀	3·99	5·19	4·51	1·91	2·58	2·22	1·84	2·31	2·03	1·17	1·19	0·85

Specimens from the 1934 and 1935 outbreaks in the Kota Belud district have been received at the Imperial Institute of Entomology. Those of the 1934 outbreak proved to be partly of the ph. *solitaria*, but mostly ph. *transiens*, though still very near *solitaria*. The 1935 lot contained very few specimens which could be classed as pure *solitaria*, and a number of typical *gregaria*, but the bulk were *transiens*. These differences between the two lots, can be better seen from the table of measurements (see Table III).

Since the two lots were from practically the same area, where no large invading swarms had been present for a considerable time, there is no doubt that a progressive transformation into the gregarious phase has been taking place in the Kota Belud district during the last two years.

As regards the ecological conditions of locust breeding in North Borneo, Mr. Keith's reports contain some extremely interesting data. First of all, the information at hand shows, as only to be expected, that the areas liable to locust invasions are those where most of the land has been cleared of forest, which in Borneo is the normal climax type of vegetation. When an area is cleared of trees for cultivation it may be used for crops, such as upland rice, for one or two growing seasons and then abandoned. Such abandoned areas may return to secondary forest, but many of them are subjected to burning, which is done for grazing and hunting purposes. This destroys most of the plants, except certain grasses, more particularly the lalang (*Imperata exaltata*, Brongn.) which has a strong root system and quickly recovers. Where burning is repeated annually, the soil may be so impoverished that the area becomes almost barren, with only a very sparse cover of lalang. Such dry, well exposed areas obviously represent a most suitable habitat for locusts, and the Kota Belud district, with the largest area of lalang and barren land in the West Coast Residency was not unexpectedly the probable source of most of the recent outbreaks. The Sook plain, where an incipient outbreak was observed in 1935, is described as a vast plain, which was forested until 1914–1915, when it was swept by fire. Now it is covered with lalang, scrub and isolated areas of secondary forest, and is subject to periodic burning.

The clearing of forests for cultivation purposes is going on steadily, since the cultivation is shifted from place to place as the soil becomes poorer. This system of shifting cultivation is, therefore, the primary factor which made the spread of locusts in North Borneo at all possible, while excessive burning produces some particularly suitable spots, which may become outbreak centres. The crowding of locusts in small areas can occur under such conditions fairly commonly, because of a rapid growth of tropical vegetation, resulting in a contraction of the suitable areas. Details of this process must, of course, be studied on the spot, but the principle is clear.

As regards the origin of locusts in North Borneo, it is not improbable that the species has been absent from the island until some swarms arriving from the Philippines found areas cleared of forest and suitable for breeding. Now, however, the locust is a permanent member of the local fauna and outbreaks can and do originate on the spot.

The dispersal of swarms in North Borneo presents some interesting features, so far as can be judged without a sufficient knowledge of the country. The map shows that the plains along the western coast are particularly affected, and a spread of swarms into the interior occurs mostly along river valleys. It is probable that the west coast is more liable to attacks either because of a larger percentage of cleared land, or because of its climate being more favourable to locusts than that of the interior and the east coast.

Philippine Islands.

A comprehensive summary of locust outbreaks in the Philippine Islands is being prepared by Dr. L. B. Uichanco of the College of Agriculture, University of the Philippines, and it will undoubtedly throw more light on the problem than it is possible for me to do, in the practical absence of detailed information. I will, therefore, restrict myself to a few general remarks.

There is little doubt that the Philippines can be rightly regarded as an area where the economic importance of the locust problem is as great as, and possibly even greater than, in China. Records of outbreaks can be found in the earliest travellers' accounts, while during the last 22 years there was not a single year when outbreaks of varying intensity were not reported in some of the islands (Goseco, 1933).

No ecological information with regard to breeding areas is available, but an outstanding feature of local agriculture is the same system of shifting cultivation as described above for Borneo. According to Whitford (1911) practically the entire land area of the Philippines was originally covered with unbroken forests. At present, however, about 40 per cent. of the whole area is grasslands, while about 10 per cent. is under cultivation. The grasslands, called locally *cogonales*, represent the product of shifting cultivation and of repeated burning of the grass. They are of two types. One type occurs on wetter and even marshy soils and is covered mostly with a dense and tall growth of *talahib*, *Saccharum spontaneum*, L. Another type, on drier soils, is composed mainly of *cogon*, *Imperata exaltata*, Brongn., which in Borneo is called lalang.

While the grasslands overgrown with *talahib* may offer excellent food conditions for hoppers and adult locusts, there can be no doubt that the real breeding areas, and more particularly outbreak areas, must be looked for in the second type of dry *cogonales* covered with *Imperata exaltata*. Moreover, since some areas of the Philippines have a climate with a prolonged dry season (Cox, 1911), it appears more promising to concentrate the attention on them. Of particular interest would be the investigation of natural grassland areas, which can presumably be found in the drier islands. The continuity of swarming during the last two decades (see above) suggests, however, that the system of shifting cultivation presents exceptionally favourable conditions for the production and the maintenance of the swarming phase. Therefore, no definite hopes for the solution of the locust problem in the Philippines can be entertained until the ecology of *cogonales* in relation to locusts is studied in detail and a system of cultivation devised which would prevent a creation of artificial outbreak centres.

Dutch East Indies.

As communicated to the Imperial Institute of Entomology by Dr. A. Reyne, there are several records of visits of locust swarms to some small islands north of Celebes. For instance, in 1923 a swarm of flying locusts was stated to have come to Nanusa Island, probably from Mindanao. A similar occurrence was reported with regard to the Talaur Islands. In 1932 a swarm was observed on the Great Sangir and on Las Palmas Islands. All these islands are between Celebes and Mindanao and the origin of swarms from the latter appears very probable. It is not improbable that some swarms may occasionally reach the northern part of the Celebes itself, but so far no records are available to show that they can establish themselves and breed there. The reasons for this can only be found on the spot.

As regards other islands of the Malayan Archipelago, the solitary phase of *Locusta* is known to occur on many of them, but no swarming has been reported. Whether this means that climatic or other conditions are unsuitable for the ph. *gregaria* is at present not known. The attention of local entomologists should be drawn to the necessity of observing solitary locusts very closely, particularly with regard to the incipient transformation into ph. *transiens*.

Formosa.

Locust outbreaks in Formosa appear to be not infrequent, but the accessible information is very meagre, being represented by a recent pamphlet published in Japanese (Sonan, Inamura & Shiraki, 1933), the contents of which can be judged only by a very short abstract (Rev. Appl. Ent., A, **21,** p. 550). According to the authors, the last case of swarming was in 1923 on the island of Samasana (or Kashoto), east of Formosa. The locusts are stated to have arrived from Luzon, Philippine Islands, and produced two generations on the island, but died out early in 1924. A map which accompanies the original work indicates by arrows and lines what are presumably the directions of swarms migrating from the Philippines northwards.

It appears that swarms may reach the Pescadores Islands (west of Formosa), the main island of Formosa and the Nambu Shoto group of the Riu-Kiu Islands, and one line of migration is indicated to lead along the east coast of Formosa beyond its northern extremity. While the invasions from the Philippines are quite probable, the possibility of locally produced outbreaks can scarcely be altogether excluded, since the solitary phase is known to occur in Formosa. Its presence of course has little meaning in itself, but cannot be ignored.

Malaya.

Our knowledge of the locust problem in Malaya dates from the last serious outbreak in the Federated Malay States which commenced in 1912 (Pratt, 1913, 1915) and attained very serious proportions in the following years. It was most unfortunate that no detailed information was published on the earliest occurrence of locusts in that country. All that was reported at that time was that locusts appeared first of all about the middle of 1912 in the neighbourhood of Port Dickson, in Negri Sembilan, on the west coast of the peninsula. During the subsequent years locusts gradually spread over most of the Federated States, extending into Perak in the north and Malacca in the south (Cowley-Brown & Burkill, 1916).

The appearance of the first swarms in a single locality near a port has led to a suggestion that the locusts were introduced on a ship. In favour of this view Pratt pointed out that the place where the locusts first occurred was no more suitable for locust breeding than many others in the country to which they spread afterwards. Another argument of the same author was that in the case of a native insect, the outbreak should have commenced in several areas simultaneously, not in a single one. Both these arguments appear purely theoretical and not based on a careful analysis of the conditions of the original outbreak near Port Dickson. This port being on the western coast of the peninsula, far away from the known outbreak areas in the Philippines and Borneo, the infestation could not have been caused by an occasional flying swarm, and an introduction of a few locusts by a ship does not appear very probable. It is true, that no locusts of the solitary phase have been found in the Federated Malay States after 1919, when the swarms finally disappeared, but on the other hand, a small incipient outbreak occurred again in 1930 in a small area on the Tumpin-Gemas road, in the south of Sembilan. This was an inland area and no question could possibly arise of the locusts not being of local origin. Only one generation of adults was produced and these proved to be of the ph. *transiens*, but no further breeding was reported (Fed. Malay States, Dept. Agric., 1931). This case proves beyond doubt that outbreaks in the Federated Malay States can arise locally, and makes the theory of an introduction in 1912 less probable.

As regards the conditions of swarm breeding, these have been studied during the great outbreak in some detail. As in the Philippines and Borneo, extensive grasslands have been artificially created in the Federated Malay States by Chinese cultivators, who during the past hundred years have been felling forest for tapioca cultivation, and abandoning the land when it was impoverished. The abandoned lands are soon covered by lalang grass (*Imperata*), and recently burnt lalang areas bearing a scanty cover are particularly suitable for egg-laying by locusts.

Another type of swarm breeding sites is presented by the abandoned tin mines, in the neighbourhood of which large areas are covered with sand and stones, with a sparse vegetation.

Rubber plantations in Malacca proved also to have conditions very suitable for the breeding of swarms (Cowley-Brown & Burkill, 1916).

It would appear that the lalang and the old mining areas in Malaya provide the conditions necessary not only for the breeding of swarms, but also for the continuous existence of the solitary phase, and for its occasional transformation into the gregarious one. A thorough survey of all areas with the sparsest vegetation and light soil may serve to determine the types of habitat particularly preferred by the solitary phase, and to be of value in the prevention of future outbreaks, which must be expected to occur sooner or later.

Indo-China.

Some specimens of the ph. *transiens* from Annam have been received by me from my friend Dr. L. Chopard, but without any definite data as to their origin.

General Considerations.

The information on the distribution and ecology of *Locusta migratoria manilensis* summarised above, although very fragmentary, is of more than local interest, since it contains an indication of a hitherto unknown type of habitat favourable for the formation of the gregarious phase. It appears appropriate, therefore, to classify the types of outbreak areas known in various subspecies of *Locusta migratoria*.

The most typical and common type of outbreak areas is that offered by the deltas of large rivers in semi-desert countries. Here belong the classical outbreak areas of *Locusta migratoria migratoria* in the deltas of rivers flowing into the Caspian, Aral and Black Seas, and into the Balkhash Lake (Uvarov, 1928). The outbreak area of *Locusta migratoria migratorioides* on the Middle Niger should also be included here, since it is actually situated in the former delta of the Niger, before its capture by another river which led to the formation of the Niger bend. The outbreak areas of *Locusta migratoria manilensis* in China also belong to this type.

A variation of the same type is observed in southern Madagascar, where the outbreak area of *Locusta migratoria capito* is found in an arid country with light soil, liable to be flooded in patches during the rains (Zolotarevsky, 1933).

A second type of outbreak area is presented by those of *Locusta migratoria rossica* in Central Russia (Predtechenskiĭ, 1928). Here the locust lives in a region generally unfavourable to it, and is restricted in its occurrence to small "islands" of dry sandy soil with sparse vegetation. Some of these "islands," during exceptionally favourable years, can become outbreak centres.

The probable outbreak areas of *Locusta migratoria manilensis* in the Philippines, Borneo and Malaya, do not enter into any of the above categories, but represent a new type. Here we find the locust inhabiting a country with a very humid tropical climate and normally covered with almost continuous forest. While the existence of the solitary phase under such conditions can be imagined possible in some open grassy areas, such as should occur on the slopes of mountains, there is obviously no chance for the development of the gregarious phase. The conditions necessary for the transformation in this case have been created artificially by the primitive methods of land utilisation. The clearing of forests led to an extension of grasslands suitable for the solitary phase, while the practice of burning grass and of using the land until it is thoroughly impoverished resulted in the creation of a habitat entirely alien to the nature of the country and eminently suitable for the locust. Moreover, this habitat should be extremely unstable and the areas occupied by it must be subject to great fluctuations, often resulting in a crowding of locusts in a small space, which would inevitably lead to a transformation into the gregarious phase.

It appears, therefore, that the gregarious phase in those countries is a product of shifting cultivation, and the problem of locust control in this case is essentially one of ecology and of agriculture. Indeed, the problem here is much more difficult to solve than in the countries where outbreak areas are natural in their origin, since there the areas can be located and kept under permanent supervision and control.

In the case of artificially created outbreak areas, one has to contend with the fact that no constancy in the areas can be expected since suitable habitats are continually produced almost everywhere.

Moreover, the experience of the Philippines and Borneo shows that under those conditions swarms of the gregarious phase are extremely persistent, and an outbreak, once it has commenced, takes a very long time to die down. It appears probable even that swarms never die down completely everywhere, while new incipient swarms arise at the same time. This state of things cannot be expected to improve in the near future, since the cultivation in those countries is developing, and more forests are being cleared. A still further increase in locust activities in the Philippine and Malayan islands, as well as the spread of the swarms to the islands so far free from them, can be predicted. The locusts will inevitably follow the development of agriculture which commences as shifting cultivation. The cost of feeding and fighting locusts will grow in proportion to the increase in agricultural production.

It would be obviously impossible in the present state of our knowledge to make any definite technical recommendations with regard to the methods of agriculture which would be less of a direct encouragement to locusts than the shifting cultivation. The problem requires careful studies on the spot, and I have already had an opportunity to suggest (Uvarov, 1934) that it would be of advantage to a large number of countries in the East, if studies of this kind were centralised in one place, and the Philippines suggest themselves as the most suitable centre for such studies. The problem is one calling for international co-operation in devising means against a pest, the importance of which is being rapidly increased by the present system of agriculture.

Acknowledgments.

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References.

Brunner von Wattenwyl, C. (1862). Ueber die von k.k. Fregatte Novara mitgebrachten Orthopteren.—Verh. zool.-bot. Ges. Wien **12,** pp. 88–96.

Cowley-Brown, P. C. & Burkill, I. H. (1916). Locusts in Malacca.—Gardens Bull. Straits Settlements, Singapore **1,** pp. 335–349, 5 maps.

Cox, A. J. (1911). Philippine soils and some of the factors which influence them. —Philipp. J. Sci. (A) **6,** pp. 279–330.

Federated Malay States. (1931). Annual Report of the Department of Agriculture for the Year 1930.—Kuala Lumpur, 31 pp.

Gater, B. A. R. (1924). Insect pests of Labuan and adjacent islands.—Malayan Agric. J. **12,** pp. 374–376.

Jagor, F. (1875). Travels in the Philippines.—London (p. 272, footnote).

Meyen, F. J. F. (1835). Reise um die Erde ausgeführt auf dem königlichen Preussischen Seehandlungs-Schiffe Prinzess Louise commandiert von Captain W. Wendt in den Jahren 1830, 1831 und 1832.—Berlin, **2,** p. 197.

Pratt, H. C. (1913). The locust pest in Malaya.—Agric. Bull. Fed. Malay States **2,** pp. 76–80.

——. (1915). The Malayan Locust (*Pachytylus* sp.).—Bull. Dept. Agric. Fed. Malay States **24,** 42 pp., 4 figs., 16 pls., 1 map.

PREDTECHENSKIĬ, S. A. (1928). *Locusta migratoria*, L. in Central Russia.—Izv. Otd. prikl. Ent., Leningrad, **3** (2), pp. 113–199, 4 figs.

SONAN, J., INAMURA, S. & SHIRAKI, T. (1933). Research on the migratory locust in Formosa and an account of their control [In Japanese.]—Publ. Bur. Ind. Govt. Formosa, no. 635, 59 pp., 4 pls. [Abstract in Rev. Appl. Ent., A, **21**, p. 550].

TSOU, T. L. (1935). The distribution of the migratory locust and ecological study of its breeding ground in China.—Agric. Sinica **1**, pp. 239–272, 11 figs., 4 pls.

UVAROV, B. P. (1928). Locusts and grasshoppers. A handbook for their study and control.—Imp. Bur. Ent., London xiii + 352 pp., 9 pls., 1 map, 118 figs.

——. (1934). The locust problem in the Pacific countries of Asia.—Fifth Pacific Science Congress, Ottawa, pp. 3455–3458.

—— & ZOLOTAREVSKY, B. N. (1929). Phases of locusts and their interrelations. —Bull. Ent. Res. **20**, pp. 261–265.

WHITFORD, H. N. (1911). The forests of the Philippines. Part 1. Forest types and products.—Bull. Bur. Forestry, Manila **10**, pp. 12–13.

WOO, F. C. & CHENG, T. S. (1934). A general investigation of the locust (*Locusta migratoria*, L.) outbreaks in China during the year 1933.—Nat. Agric. Res. Bur., Nanking, Spec. publ. no. **5**, 42 pp., 6 figs.

ZOLOTAREVSKY, B. N. (1933). Contribution à l'étude biologique du criquet migrateur (*Locusta migratoria capito*, Sauss.) dans ses foyers permanents.—Ann. Epiphyt. **19**, pp. 47–142, 10 figs., 1 pl., 1 map.

LOCUSTA MIGRATORIA MIGRATORIOIDES, R. & F.: AN ECOLOGICAL RECONNAISSANCE OF THE SUSPECTED MIDDLE NIGER OUTBREAK AREA.

(PLATES III–V & MAP.)

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I. Introduction.

The present paper is an account of a preliminary reconnaissance, undertaken during the wet season of 1932, of the suspected middle Niger outbreak area of the migratory locust, *Locusta migratoria migratorioides*, R. & F.

My tour was arranged by the Governments of Nigeria and French West Africa, and I wish to acknowledge the co-operation and hospitality of the many French officials of Senegal and the Soudan whom I met during my tour in the French Colonies. I also wish to thank the following for their help : the Director of the Imperial Institute of Entomology for having my insect collections identified ; the Director of the Royal Botanic Gardens, Kew, for having my plant collections analysed ; and especially Dr. B. P. Uvarov for his valuable help and advice throughout the work. I also wish to record the good work put in by Mr. Akalonu, a native assistant of the Nigerian Agricultural Department, who died shortly after the conclusion of these investigations.

In a previous paper (9) an analysis was made of all the records on the swarming of the *Locusta migratoria migratorioides* in Africa collected by the Imperial Institute of Entomology prior to May 1931. It was then concluded that the present widespread outbreak of this locust in tropical Africa was of a single origin and that the initial transition from the solitary to the gregarious phase occurred in 1928 in the lake districts of the middle Niger, between Segou and Timbuctoo.

Uvarov (13, 14) has recently brought the history of the invasion up to date and has been able to add several important records. Coleno (4) has studied the early swarming in the French Soudan ; he has given additional and definite records of the 1928 swarms and states that there were no swarms of this locust in this region in 1927. Coleno describes how, in June 1928, a severe infestation of hoppers was reported along the River Diaka, near Diafarabe, and that specimens of adults hatched from them were identified as the swarming phase of *L. m. migratorioides*, R. & F. These specimens are now in Paris. During the beginning of July further bands of hoppers were reported close to the River Bani near San and Mopti, though no specimens were identified.

It is now generally considered that the present outbreak of the migratory locust started up in the middle Niger in the wet season of 1928, and the main object of the reconnaissance described in this paper was to initiate a study of all factors that might assist the transition from the solitary to the gregarious phase in this region, and to try to understand why this change occurred in 1928. The first important points to be elucidated were the distribution of the solitary phase geographically and ecologically, and to determine the annual life-cycle under the various climatic conditions that obtain between Segou and Timbuctoo, with special reference to how the insect lives through the dry season and how it is affected by the river floods. In order to obtain a clear picture of the region, it was intended to carry out a survey of the general physiographic features, the principal vegetational and insect communities, and the aerial and edaphic conditions.

I landed at Dakar on 5th April, and travelled by rail to Bamako, the capital of the Soudan, arriving there on the 14th. I moved on to Segou by road on the 19th. Subsequently I travelled mainly in a small barge kindly placed at my disposal by the Lieutenant-Governor, French Soudan, and during the rest of my tour I remained almost entirely on the River Niger, its tributaries and lakes, with occasional short excursions inland. During most of the river journeys periodic halts were made for brief surveys on the river banks. I returned to Segou on 28th September and sailed from Dakar on 18th October. From 8th July to 18th August I was accompanied by M. Coleno of the French Colonial Agricultural Service, and since my departure from West Africa M. Coleno has been continuing the observations in the middle Niger under M. Zolotarevsky, who has published short notes on his preliminary work ([16, 17]). Throughout the tour I was accompanied by a trained entomological assistant, the late Mr. Akalonu, and I also employed a native clerk.

II. TOPOGRAPHY.

1. River System.

General.

The region covered by the survey consists of the valleys of the Niger from Segou to Timbuctoo, and of its tributary the Bani from near San to Mopti. For convenience in analysing some of the data the region has been divided into three areas as follows :—(*a*) South-western area : Segou, Macina, Diafarabe, San, Seyna ; (*b*) Central area : Mopti, Konna, Korienze, Debo, Sarafere ; (*c*) North-eastern area : Horo, El Oualadji, Dire, Kabara, Timbuctoo.

The whole region lies roughly between latitudes 13° and 17°N. Throughout the area the general course of the river is from south-west to north-east, from the forest to the desert. The distance by river from Segou to Timbuctoo is roughly 415 miles, and San is about 100 miles up the Bani from Mopti. A good general description of this part of the Niger, written by M. Bélime, the acknowledged authority, is quoted by Coleno ([4]), while in my previous paper ([9]) several references are given to studies of the peculiar regime of this interesting river.

At the commencement of the tour the river was at its lowest level, and the main stream from Segou to Mopti was flowing along a devious channel amongst undulating sandhills. Most of the course is clearly defined, the sandhills being bordered by sand and clay cliffs from 15 to 20 feet high. In some regions the river divides into several channels forming large and small islands. From bank to bank the bed of the river varies from 900 to 1,300 yards wide.

The inundation zone commences at Sansanding (25 miles N.E. of Segou), and from this point branches of the river diverge on either bank, though above Diafarabe none is running during low water. At Diafarabe the river divides, the main stream continues to Mopti, and the River Diaka flows N.E. to Lake Debo. The Diaka is an important branch open to small canoe traffic throughout the year, and is similar in character to the main stream. At Mopti the Niger is joined by the important tributary, the River Bani, flowing from the south-west.

Around Diafarabe, down the Diaka to Debo and down the Niger below Mopti, the character of the valley is different. The banks are not so high, and on either side of the river lie great level plains subject to extensive inundation during the flood. The banks are rather higher between Diafarabe and Mopti, and consequently inundation is not so complete there.

Forty miles north of Mopti the Niger divides again, the main stream flowing into Lake Debo—a large lake covering 325 square miles at low water—while the River Koli-Koli flows N.E. through Lake Korienze. Two main streams leave Debo ; the Bara-Issa turns eastwards and joins the Koli-Koli at Sarafere, and the Issa-Ber flows north past Niafunke to rejoin the combined Bara-Issa and Koli-Koli at El Oualadji. From here the Niger flows in one main course past Kabara, the port for Timbuctoo.

The whole of the country from Sansanding to Kabara is a plain broken by occasional hills and outcrops, and covered by an anastomosis of irregular channels and lakes, which are especially numerous in the region between Debo and Dire (Plate IV, fig. 1). On the right bank south-east of Dire there is a complicated system of lakes, Korayou, Hougoundou, Do and Niangaye, which fill and empty with the rise and fall of the flood.

On the left bank there are three large lakes, Télé, Faguibine and Horo, which lie below the level of the Niger. As the flood approaches high water the river overflows into Télé ; and when Télé reaches a certain height Faguibine is filled. Faguibine is therefore flooded only by exceptionally high floods and the water is unable to flow back into the river. It is interesting to note that Faguibine was exceptionally high in 1893, as shown by the maps made by Joffre during the conquest of this region, just after the commencement of the last outbreak of *L. m. migratorioides*. According to the natives it was also high in 1890, 1894 and 1896, it was partly flooded in 1917 and 1918, and there was a big flood in 1924–25, and again in 1928 just after the commencement of the present outbreak.

The whole of this section of the Niger is flowing across a slightly inclined plain which slopes down gradually from south to north so that inundations are more extensive on the north bank. The Bani is similar in character to the Niger and the main inundation zones lie near San, Djenne and Mopti. At high water the two rivers are joined by a network of streams and floods in the region of Macina and Djenne. During high water the Niger is open for large steamboats between Koulikoro (near Bamako) and Kabara, via Debo and the Issa-Ber. Smaller boats use the Bani.

The source of the Niger lies in Sierra Leone, but the main basin of the head-waters is in the mountainous regions of French Guinea, and it is likely that the amount of rainfall there largely determines the annual flood-level. The annual rainfall in that region is roughly 100 inches ; the rains commence in February and the maximum monthly fall is in July (about 20 inches). The maximum flood reaches Segou at the end of September or early in October. It arrives at Diafarabe and Mopti at the end of October or early November, and at Niafunke in mid-December.

The basin of the head-waters of the Bani lies in eastern Guinea and north-western Ivory Coast, where the annual rainfall is about 70 inches. The rains start a little earlier than further west, the maximum monthly fall being in July, but it is only about 12 inches. The maximum flood reaches Benenigeni, near San, in early October. Table I shows details of the flood in the various reaches under normal conditions from data supplied by the French Government.

As has been stated, nearly the whole region of the middle Niger is covered by a network of small channels. Some of these are narrow, deep and well-defined, and may contain stretches or pools of water even throughout the dry season ; others are

TABLE I.

Average Regime of Rivers Niger and Bani.

	Average date of low water	Average date of high water	Rise and fall in metres
River Niger—			
Segou	March, April	Sept., October	5·4
Diafarabe	March, April	Sept., October	5·5
Mopti	?	November	6·2
Niafunke	June	December	5·4
River Bani—			
San	June (?)	Early October	10·0

mere lengthy depressions which may or may not remain swampy in the dry season. Scattered over the plains there are many large circular depressions, which frequently hold water in the dry season, though most dry up and become bare expanses of dried fissured clay. At the time of the flood canoes can pass in nearly every direction over the plains, as the central area is then one vast lake some 300 miles long and 100 miles wide, broken by occasional outcrops, sandhills and small islands on which the villages are perched.

Annual Variations of the Regime.

In examining the possible reasons for the development of the swarming phase in the middle Niger, it was considered that variations in the time and extent of the river flood might be significant. Unfortunately, river height data are very incomplete and are not available over any long period. The minimum and lower water-levels can have little effect on the ecology of *Locusta* since, until the river has risen several metres, it is still confined to the main channel, gradually rising over the sandhills, which are not inhabited by the *solitaria*.

TABLE II.

Annual Variation in Height (Metres) and Date of Maximum Flood.

	Segou		*Diafarabe*		*Mopti*		*Niafunke*	
	Height	Date	Height	Date	Height	Date	Height	Date
1922			5·63	Oct. 25–27				
1923			5·87	Sept. 29–Oct. 7				
1924			5·94	Sept. 17–19				
1925			5·49	Oct. 25–Nov. 1			6·55	Jan. 1 (1926)
1926			5·50	Sept. 26–Oct. 3			5·81	Nov. 25
1927	5·70	Oct. 10–15	5·53	Oct. 19–30			6·33	Dec. 25
1928	6·28	Sept. 25			6·30	Nov. 5–15	6·53	Dec. 20–25
1929							6·63	Dec. 20
1930					6·17	Oct. 30–Nov. 10	6·11	Dec. 15

The maximum flood-level does not vary greatly year to year, as shown in Table II, and for the three years when the Diafarabe and Niafunke records overlap it appears that there is no close correlation between the height in these two reaches of the river.

From these figures one would say that 1924 and 1929 were high flood years, that the flood of 1927 was slight, that the flood was generally lowest in 1926 and that it was also low at Diafarabe in 1925.

The same table shows that the date of the maximum flood does vary considerably, *e.g.*, at Diafarabe from 17th September (1924) to 25th October (1922 and 1925), and at Niafunke from 25th November (1926) to 1st January (1925/26). Thus in 1926 the flood was early and in 1927 late.

Were more data available it would have been valuable to analyse the rate at which the river rose each year and the dates at which the various plant associations were flooded in each locality. The contours of the middle Niger area are very slight and a difference in level of only a foot or two may mark one plant association from another ; a flood of 6·6 metres may mean that a whole plain is submerged, and one of 5·8 metres may leave quite a number of ridges dry. Hoppers may be driven gradually to these ridges and female locusts may concentrate on them to oviposit.

Presuming that the formation of incipient swarms in the middle Niger is in some way related to the flood, the ultimate problem of preventing locust outbreaks would be greatly facilitated if it were possible to forecast the heights and dates of flood from the rainfall records earlier in the year in the Guinea highlands. Such rainfall records are, however, only available for 1923/30 for Kouroussa, Mali and Mamou, and for 1923/26 for Beyla.

The time of commencement of these rains may be shown by the monthly rainfall April–July, while the total fall during this period might be expected to be related to the height of the flood (Table III). It will be seen that 1926 stands out as a year of late commencement of the rains in the highlands and low total rainfall during the first half of the rainy season. As stated above, the flood was early in 1926, so that a far more detailed analysis of the rainfall in the upper Niger is required before it is possible to account for the varying time of the flood, though it appears that this may vary with the time of the maximum rainfall in the southern middle Niger region, since it is shown in a later section that the rains were unusually early there in 1926. On the other hand the total rainfall April–July in the Guinea highlands appears to be connected with the height of maximum flood, for 1924 stands out as a year of exceptionally heavy rain and rather high flood.

TABLE III.

Rainfall (mm.) in Guinea Highlands.

Year	Apr.	May	June	July	Total	Year	Apr.	May	June	July	Total
			Kouroussa						Mali		
1923	114	73	193	328	708	1923	4	414	—	4,994	—
1924	39	133	154	400	726	1924	137	76	512	442	1,167
1925	38	209	248	311	806	1925	24	49	371	432	876
1926	13	101	242	234	590	1926	8	39	213	348	608
1927	178	458	—	—	—	1927	21	104	189	351	665
1928	26	132	83	206	447	1928	29	136	167	311	643
1929	62	77	278	192	609	1929	2	70	376	278	726
1930	52	117	312	393	874	1930	9	51	360	286	706
			Mamou						Beyla		
1923	225	172	330	210	937	1923	—	156	140	267	—
1924	86	207	566	291	1,150	1924	83	106	246	219	654
1925	28	172	299	224	723	1925	130	135	256	373	894
1926	49	81	116	215	461	1926	138	23	111	97	369
1927	86	192	259	328	865						
1928	—	208	213	—	—						
1929	143	201	336	279	959						
1930	102	177	240	410	929						

2. Orography.

This section of the Niger valley is bordered in the south-east by mountainous country, and the foothills approach close to the river between Mopti and Korienze, and to the Bani between Mopti and San. On the left bank the country is comparatively level except for ranges of hills normally covered with scree near the lakes around Goundam. In the valley itself there are massive granite outcrops near Lake Debo—Rocher Marie Therese (230 ft. high), Mt. St. Henri, and Mt. St. Charles.

West of Sansanding the country is an undulating plain, the ridges having been formed from wind-blown sand. The inundation zone proper consists essentially of a vast and nearly level plain, but there are occasional quite high ridges of sand-hills, and many small circular " islands " of heavy clay, a few hundred yards in diameter, which are either covered by dense thorn thickets or are the sites of villages and cemeteries.

The first large open plains begin a few miles west of Diafarabe, especially on the north bank. Up the Diaka, the land is level to the south, but there are considerable ridges near Dia and Tenenkou to the north. Between Diafarabe and Mopti the country is again undulating and rather similar to the Macina district, though it flattens out again near Mopti at the junction of the Niger and Bani Rivers. East of Mopti there is a vast low-lying plain, with a broad belt of undulating sandy country extending to the base of the Hobo Hills. These hills, near Bandiagara, are very rocky and precipitous with lateritic plateaux.

Up the Bani the country is again undulating but near Sofara the Bandiagara hills come close to the south-east bank. It flattens out again near Djenne, and also where several small tributaries enter the river, *e.g.*, near San.

Down the Niger from Mopti past Konna the inundated area is not extensive on the right bank, and along this bank of the Koli-Koli low hills, some rocky, others mostly sand-dunes, come close to the river and shores of Lake Korienze. The eastern shore of Debo and the banks of the Bara-Issa and Issa-Ber are well-defined, and frequently bordered by high sand-hills. From this district to Timbuctoo the country is typically low-lying, inundated areas alternating with broad belts of sand-dunes usually running north to south. Near Sarafere the plains may be some two or three miles wide with frequent swamps, but towards the north the low-lying country decreases and the sand increases, until, near Timbuctoo, the only low-lying areas are close to the Niger banks. Near Kabara this plain is very extensive.

Table IV shows the heights of various towns above sea-level.

TABLE IV.

Town	Height in feet
Bandiagara	1,276
Bamako	1,134
Segou	1,023
Sansanding	1,006
Diafarabe	934
San	934
Djenne	917
Mopti	867
Niafunke	851
Kabara	833

III. CLIMATE.

1. General.

The climate of this part of the Niger valley is fairly simple, with a gradation from the moister southern province to the more desert conditions near Timbuctoo. A line running just north of Diafarabe through Mopti to Douentza demarcates the southern region with the " Soudanian " climate from that with the " Sahelien." The region with the " Saharan " climate commences some 60 miles north of Timbuctoo.

There are two main seasons : the wet or rainy season, during which the humidity is high, the wind blows from the south-west, and the temperatures are comparatively low with but slight diurnal variations ; and the dry season, typified by very arid conditions with the strong north-east harmattan wind and high day and low night temperatures. The gradation from the south to the north is well shown by the average monthly rainfall figures set out in Table V with the stations of the area and those lying immediately adjacent arranged in order of magnitude of their average rainfall. It will be seen that San, the southernmost station in the area, has an average total rainfall of 29·3 ins. with a dry season of roughly 5 months (November to March), whilst Kabara, the northernmost station, has an average rainfall of 8·3 ins. with a dry season of roughly 9 months (October to July). These two stations are only 265 miles apart, and therefore the climatic gradient is unusually steep. The rainfall of the whole area is of the tropical type with a single maximum in August or July.

2. Climatic Conditions during the Survey.

The conditions of the survey did not allow any long series of exact climatological data to be taken, and I have had to rely largely on the official records taken by the few stations scattered over the district. These records were kindly supplied by the Director of the Service Meteorologique of French West Africa.

Though there had been a few traces of rain before I reached Segou, the survey really commenced in typical dry season conditions with the harmattan still blowing. The rains set in in early June during the journey from Mopti to San. I then moved down the Niger to Timbuctoo more or less with, though rather slower than, the advance of the rains from the south-west, so that my stay in Timbuctoo almost coincided with the height of the rainy season there. Similarly the return journey to Segou followed the retreat of the rains, and the survey closed with the commencement of the dry season.

Rainfall.

Table VI gives the official monthly 1932 rainfall records from twelve stations in and around the middle Niger district. Tables X–XIII show how the 1932 rainfall, partly expressed as degrees of wetness, compared with that of other years. In a previous paper (¹⁰) it was indicated that the effect of precipitation appeared to be expressed better as monthly degrees of wetness than as monthly rainfall. This is calculated as follows :—

$$\text{M.D.W.} = \frac{R \times D}{10}$$

where R = total monthly rainfall in inches, D = number of days rain, and M.D.W. = monthly degree of wetness.

The total rainfall was generally below the average owing mainly to subnormal rains in the July/September period. There was no appreciable rainfall during the previous dry season except at Koutiala and Douentza. The rains started rather later than the average in the southern and central provinces, though they set in at a normal

TABLE V.

Average Rainfall (ins.).

	Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Period Totals		
															Apr./ June	July/ Sept.	Oct./ Nov.
1. Sikasso ...	1921–32	0	0·9	0·4	2·6	5·2	7·4	10·4	13·0	12·3	4·7	0·8	0	57·7	15·2	35·7	5·5
2. Bougouni ...	1922–32	0	0	0·3	1·7	4·9	6·0	10·0	12·6	10·9	2·4	0·5	0	49·3	12·6	33·5	2·9
3. Bamako ...	1921–32	0	0·1	0·1	0·7	3·3	4·3	8·6	14·3	7·8	2·4	1·1	0	42·7	8·3	30·7	3·5
4. Nienebale ...	1922–32	0	0·2	0·1	1·2	2·9	6·0	9·9	11·6	6·7	2·0	0·1	0·1	40·8	10·1	28·2	2·1
5. Koutiala ...	1921–32	0	0·1	0·1	1·6	2·3	5·5	9·1	7·9	6·0	1·7	0·2	0	34·5	9·4	23·0	1·9
6. San	1921–32	0	0	0·1	0·7	1·6	5·2	6·9	8·6	5·0	1·0	0·2	0	29·3	7·5	20·5	1·2
7. Segou	1920–29	0	0·1	0·1	0·6	1·4	3·6	6·8	9·5	4·8	0·8	0	0	27·7	5·6	21·1	0·8
8. Bandiagara ...	1921–32	0	0	0	0·7	0·6	3·4	5·9	7·5	4·7	1·3	0·3	0	24·4	4·7	18·1	1·6
9. Diafarabe ...	1923–28	0	0	0	0·3	0·6	3·1	6·9	6·9	4·3	0·9	0	0	23·0	4·0	18·1	0·9
10. Macina ...	1926–32	0	0	0·1	1·0	1·1	2·9	6·3	7·1	3·4	0·4	0	0·2	22·5	4·0	16·8	0·4
11. Mopti ...	1921–32	0	0	0	0·4	1·4	2·7	6·5	7·3	2·9	0·4	0	0	21·6	4·5	16·7	0·4
12. Douentza ...	1926–32	0	0·1	0	0·1	1·2	2·9	5·1	5·9	3·0	0·8	0	0	19·1	4·2	14·0	0·8
13. Niafunke ...	1921–32	0	0	0	0·2	0·1	0·8	3·2	5·3	3·2	0·4	0	0	13·2	1·1	11·7	0·4
14. Goundam ...	1921–32	0	0	0	0·1	0·2	0·8	2·8	3·5	2·1	0·1	0	0	9·6	1·1	8·4	0·1
15. El Oualadji ...	1926–31	0	0	0	0·1	0·2	0·7	3·2	2·7	1·9	0·2	0	0	9·0	1·0	7·8	0·2
16. Dire	1921, 23, 24, 26–32	0	0	0	0·1	0·1	0·5	2·5	3·5	1·9	0·3	0	0	8·9	0·7	7·9	0·3
17. Kabara ...	1921–32	0	0	0	0·1	0	0·5	2·1	3·7	1·8	0·1	0	0	8·3	0·6	7·6	0·1
18. Rharous ...	1926–32	0	0	0	0	0·2	0·4	2·0	1·9	0·6	0·1	0	0	5·2	0·6	4·5	0·1
19. Araouan ...	1926–32	0	0	0	0	0	0·2	0·4	2·0	0·7	0	0	0	3·3	0·2	3·1	0

TABLE VI.

Rainfall, 1932 (*ins.*).

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Total	Percentage deviation from average			
													Total	Apr./June	July/Sept.	Oct./Nov.
5. Koutiala ...	—	0·4	0	0	2·5	2·9	12·0	2·8	7·8	0·7	0	29·1	−16	−42	−4	−68
6. San	0	0	0	0·3	0·5	5·8	8·7	10·4	2·4	0·3	0	28·4	− 3	−12	+3	−75
8. Bandiagara ...	0	0	0	0	0·9	3·9	—	—	—	—	—	—	—	+4	—	—
10. Macina ...	0	0	0	—	0·1	1·7	8·7	6·6	1·4	0	0	18·5*	−18	—	−1	−100
11. Mopti ...	0	0	0	0·1	4·3	1·6	10·4	7·9	0·2	—	—	24·5*	+13	+35	+13	—
12. Douentza ...	—	0·4	—	0	1·8	1·5	3·5	7·6	1·9	0	0	16·7*	−13	−19	−11	−87
13. Niafunke ...	0	0	0	0	0·4	0·6	1·5	1·3	1·4	0	0·2	5·4	−59	+18	−65	−50
14. Goundam ...	0	0	0	0	0·5	0·9	3·6	—	1·7	0·1	—	—	—	+45	—	—
16. Dire	0	0	0	0	0	0·6	2·0	—	—	—	—	—	—	−14	—	—
17. Kabara ...	0	0	0	0	0	0·7	2·6	1·9	2·6	0·2	0	8·0	−4	+17	−5	+100
18. Rharous ...	0	0	0·1	—	—	0·4	3·0	0·2	0·4	0·3	0	4·4*	−5	—	−20	+200
19. Araouan ...	0	0	0	0	0	0	0·7	0·7	0·6	—	0	2·0*	−39	−100	−35	—

No December records are available but probably no appreciable rain fell at any station. The records for those stations marked * are incomplete, though the total rainfall was probably little above that given.

TABLE VII.

Rainfall, 1928 (*ins*.).

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Percentage deviation from average			
														Total	Apr./ June	July/ Sept.	Oct./ Nov.
5. Koutiala...	0	0	0·1	1·1	2·0	2·6	10·7	8·9	6·5	2·7	0	0	34·6	+1	−39	+13	+42
6. San ...	0	0	0	0·4	0·9	3·7	4·6	6·2	8·3	1·0	0	0	25·1	−14	−33	−7	−17
7. Segou ...	0	0	0	2·3	1·0	4·6	5·5	10·9	5·5	1·5	0	0	31·3	+13	+41	+4	+87
8. Bandiagara	0	0	0	1·3	1·1	2·9	4·3	—	2·6	1·4	0	0	—	—	+13	—	−12
9. Diafarabe	0	0	0	0·2	0·6	0·7	—	—	—	0·6	0	0	—	—	−62	—	−33
10. Macina ...	—	—	—	2·2	0·9	0·7	6·0	10·3	2·7	—	0	0	—	—	−5	+13	—
11. Mopti ...	0	0	0	1·6	0·2	1·7	7·4	10·1	2·1	0·1	0	0	23·2	+7	−22	+17	−75
12. Douentza	0	0	0	0·3	0·6	2·0	6·0	5·6	2·0	1·5	0	0	18·0	−5	−31	−3	+87
13. Niafunke...	0	0	0	0	0	0·2	2·8	2·9	1·5	0	0	0	7·4	−44	−82	−40	−100
15. El Oualadji	0	0	0	0	0	0·1	1·5	5·6	0·9	0	0	0	8·1	−10	−90	+3	−100
16. Dire ...	0	0	0	0	0	0·1	1·7	6·7	0·8	0·2	0	0	9·5	+7	−86	+16	−33
17. Kabara ...	0	0	0	0	0	0·4	2·2	6·6	0	0	0	0	9·2	+10	−33	+16	−100
19. Araouan ...	0	0	0	0	0	0	—	2·0	0·3	0	0	0	—	—	−100	—	—

TABLE VIII.

Rainfall, 1927 (*ins.*).

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Percentage deviation from average			
														Total	Apr./ June	July/ Sept.	Oct./ Nov.
5. Koutiala ...	0	0	0	2·6	2·4	6·0	5·5	10·1	3·8	1·1	0·2	0	31·7	−8	+17	−16	−32
6. San ...	0	0	0	1·6	2·0	9·2	7·4	11·4	9·2	1·5	0·8	0	43·1	+47	+71	+37	+92
7. Segou ...	0	0	0	0·8	1·7	7·7	7·4	15·6	4·0	0·6	0	0	37·8	+36	+82	+28	−25
8. Bandiagara	0	0	0	0·9	0·3	3·8	6·3	6·4	5·4	2·3	0·7	0	26·1	+7	+6	±0	+87
9. Diafarabe...	0	—	0	0·2	0·3	4·2	3·0	7·8	2·4	2·2	0	0	20·1	−13	+17	−27	+144
10. Macina ...	—	—	—	—	1·3	3·6	7·7	10·4	6·6	5·6	0	0	—	—	—	+47	+1300
11. Mopti ...	0	0	0	1·2	0·2	3·1	4·0	7·6	1·9	0·7	0	0	18·7	−13	±0	−19	+75
12. Douentza...	0	0	0	0	0·6	3·5	7·3	7·1	6·0	0·7	0	0	25·2	+32	−2	+46	−12
13. Niafunke ...	0	0	0	0·2	0	0·6	0·9	7·7	3·9	0·9	0	0	14·2	+8	−27	+7	+125
14. Goundam...	0	0	0	0	0·1	0·3	4·6	6·4	3·3	0	0	0	14·7	+53	−64	+70	±0
15. El Oualadji	0	0	0	0·2	0	0·1	2·5	2·5	2·7	0·8	0	0	8·8	−2	−70	−1	+300
16. Dire ...	0	0	0	0·1	0	0·2	2·4	4·4	2·6	0·4	0	0	10·1	+13	−57	+19	+33
17. Kabara ...	0	0	0	0	0	0·1	2·5	6·7	3·9	0	0	0	13·2	+59	−83	+72	−100
19. Araouan ...	0	0	0	0·2	0	0·1	0·3	0	0·2	0	0	0·2	1·0	−70	+50	−84	±0

TABLE IX.

Rainfall, 1926 (*ins.*).

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Percentage deviation from average			
														Total	Apr./ June	July/ Sept.	Oct./ Nov.
5. Koutiala ...	0	0	0	0·3	1·6	8·4	10·6	4·6	2·3	0·2	0·6	0	28·6	−17	+10	−23	−58
6. San ...	0	0	0	0	0·9	7·1	4·9	5·3	1·9	1·1	0·4	0	21·6	−26	+7	−41	+67
7. Segou ...	0	0	0	0	2·2	6·4	4·1	2·9	1·6	2·0	0	0	19·2	−31	+53	−59	+150
8. Bandiagara	0	0	0	0	0·9	6·2	3·0	5·8	5·9	0·9	0·5	0	23·2	−5	+51	−19	−13
9. Diafarabe...	—	—	—	0·3	0·4	4·7	5·1	2·5	1·8	0·5	—	—	—	—	+35	−48	—
10. Macina ...	0	0	0	1·5	1·5	6·9	5·8	3·6	1·7	0	0	0	21·0	−7	+147	−34	−100
11. Mopti ...	0	0	0	0	0·4	6·2	2·9	2·4	1·9	0·3	0	0	14·1	−35	+47	−57	−25
12. Douentza...	0	0	0	0	1·6	4·4	3·2	5·3	2·1	0·4	0	0	17·0	−11	+43	−24	−50
13. Niafunke ...	0	0	0	0	0	0·2	3·9	13·6	2·2	0	0	0	19·9	+51	−91	+68	−100
14. Goundam...	0	0	0	0	0	1·2	4·8	2·0	0	0	0	0	8·0	−17	+10	−19	−100
15. El Oualadji	0	0	0	0	0	0·5	5·5	1·1	1·9	0	0	0	9·0	±0	−50	+9	−100
16. Dire ...	0	0	0	0	0	0·5	2·5	1·5	1·8	0	0	0	6·3	−29	−29	−27	−100
17. Kabara ...	0	0	0	0	0	0·5	3·0	2·3	0·7	0	0	0	6·5	−22	−17	−21	−100
19. Araouan ...	0	0	0	0	0	1·6	0·4	0	0	0	0	0	2·0	+39	+700	−36	±0

TABLE X.

Time of onset of rains.

(Date when wetness reached 2°.)

	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932
San	—	June 7	May 28	June 1	June 10	May 24	May 19	June 9	May 20	May 20	June 20	June 3
Segou	June 23	June 17	June 15	June 21	June 15	May 23	May 20	May 25	June 21	—	—	—
Bandiagara ...	—	June 21	July 19	June 21	May 30	May 25	June 7	June 23	May 28	July 3	June 21	June 3
Diafarabe	—	—	—	June 3	June 18	June 15	June 2	June 2	—	—	—	—
Macina	—	—	—	—	—	May 19	—	June 25	May 30	June 15	July 3	June 20
Mopti	June 25	May 22	June 22	—	May 28	May 28	June 1	June 21	May 2	June 28	—	June 23
Douentza	—	—	—	—	—	May 25	June 4	June 21	—	June 20	June 9	June 28
Niafunke	July 13	July 15	July 3	June 24	July 3	July 9	July 21	July 25	Aug. 3	July 17	July 7	N.
Goundam	Aug. 2	—	N.	June 30	Aug. 9	July 2	July 6	—	July 30	July 14	July 3	July 6
El Oualadji ...	—	—	—	—	—	June 30	N.	July 21	July 3	July 13	N.	—
Dire	July 23	—	—	—	—	N.	July 24	July 18	July 25	July 3	N.	—
Kabara	—	Aug. 13	July 11	June 30	July 30	July 3	July 15	July 15	July 25	N.	N.	N.

N=wetness never reached 2°.

TABLE XI.

Rate of Onset of rains.

(Number of days during which wetness rose from 0·5°–2°.)

	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932
San	—	22	22	12	16	6	10	16	10	30	20	14
Segou	28	22	78	56	20	24	12	58	32	—	—	—
Bandiagara	—	14	106	6	10	6	12	28	12	10	6	14
Diafarabe	—	18	16	20	10	12	—	—	—	—	—	—
Macina	—	—	—	—	—	22	—	72	16	33	28	18
Mopti	9	4	22	—	8	8	9	14	11	64	—	52
Douentza	—	—	—	—	—	8	14	14	—	54	14	22
Niafunke	15	21	9	6	10	14	4	25	70	21	25	N.
Goundam	20	—	N.	7	54	16	12	—	26	23	26	24
El Oualadji	—	—	—	—	—	9	N.	19	21	16	N.	—
Dire	11	—	—	—	—	N.	24	13	12	11	N.	—
Kabara	—	18	18	8	16	12	19	18	42	N.	N.	N.

N = wetness never reached 2°.

TABLE XII.

Rainfall, April–June, Percentage Deviation from Average.

	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932
San	—	−14	+13	−30	+14	+7	+71	−33	+12	+23	−48	−12
Segou	−70	−46	+23	−45	−46	+53	+82	+41	−36	—	—	—
Bandiagara	—	—	−38	−9	+4	+51	+6	+13	+18	−48	−40	+4
Diafarabe	—	—	—	+73	−46	+35	+17	−62	—	—	—	—
Macina	—	—	—	—	—	+147	—	−5	+37	+29	−50	—
Mopti	—	+5	−20	−37	−2	+47	±0	−22	+39	−20	+34	+35
Douentza	—	—	—	—	—	+43	−2	−31	—	+21	−16	−19

TABLE XIII.

Month of Maximum Rainfall.

	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932
San	—	July	Aug.	July	Aug.	June	Aug.	Sept.	July	Aug.	Aug.	Aug.
Segou	Aug.	July	Aug.	Aug.	—	June	Aug.	Aug.	—	—	—	—
Bandiagara	Aug.	Aug.	Sept.	Aug.	Aug.	June	Aug.	—	June	Sept.	July	—
Diafarabe	—	—	Aug.	July	July	July	Aug.	—	—	—	—	—
Macina	—	—	—	—	—	June	Aug.	Aug.	Aug.	July	July	July
Mopti	July	Aug.	Aug.	July	Aug.	June	Aug.	Aug.	Aug.	July	—	July
Douentza	—	—	—	—	—	Aug.	July	July	—	Aug.	July	Aug.

rate except at Mopti. Though the actual May rainfall of the central province was above that of the southern province, the rains, expressed as wetness, gradually extended, as usual, from the south-west to the north-east. They terminated earlier than usual except in the extreme north.

Temperature.

No official temperature records are available, and only periodical records were taken by myself, usually under rest-house verandahs in the shade of a tree, or in the barge. These are summarised in Table XIV.

TABLE XIV.

Summary of Shade Temperature (Fahr.) and Relative Humidity Readings.

Month	Localities	9 a.m.		3 p.m.	
		Temperature	% Rel. hum.	Temperature	% Rel. hum.
April ...	Segou ...	90·4	2·4	98·7	16·0
May ...	Macina Diafarabe	89·1	53·5	98·5	39·0
June ...	Mopti Benenigeni San	90·9	53·0	100·2	31·0
July ...	Saraféré ...	82·3	72·0	85·8	67·0
Aug. ...	Dire ...	90·0	65·0	97·2	60·0
Sept. ...	Diafarabe Tenenkou	81·2	82·0	—	—

TABLE XV.

Relative Humidity, 1932.

	January	February	March	April	May	June	July	August	September	October
Bamako ...	34.22.26					80.41	84.62.72	87.71.77	87.64.78	77.56.61
Av. ...	27					—	73	78	76	65
Mopti ...	70 & 51	63 & 36	58 & 32		59.48.47			84.80.81	83.79.79	82.76.77
Av. ...	—	—	—	—	51			82	80	78
Kabara ...	58 & 43	52.45.47	40 & 17	22.13.15	36.26.27	46.29.30	63.44.44	69.52.56	71.—.62	
Av. ...	—	48	—	17	30	35	50	59	—	

Relative Humidity.

Relative humidity records taken during the survey are summarised in Table XIV. Official records are also available from three stations (Table XV), but there are many lacunae and the readings have been taken at various times :—

At Bamako the readings were taken at 8, 13 and 18 hours.

At Mopti, Jan.–March, maximum and minimum humidities only. May and Oct., taken at 7, 14 and 21 hours. Aug. and Sept., taken at 8, 13 and 18 hours.

At Kabara, Jan. and March, maximum and minimum humidities only. Feb. and Apr.–Sept., taken at 8, 13 and 18 hours. The following few early morning records were also taken :—

TABLE XVI.

Date	Locality	Position	Dry bulb	Relative humidity
				Per cent.
May 26 ...	Diafarabe, 6 a.m.	T	79·3°	81
June 12 ...	Mopti, 6.25 a.m.	B	75·4°	70
June 20 ...	Benenigeni, 6.10 a.m.	T	75·9°	74
,, ...	,, 6.50 ,, ...	T	78·9°	60
,, ...	,, 7.5 ,, ...	T	81·0°	58
,, ...	,, 7.35 ,, ...	T	82·1°	57
,, ...	,, 7.50 ,, ...	T	85·1°	51
July 20 ...	Nr. Korienze, 7.0 a.m.	B	72·0°	
Aug. 3 ...	Dire, 5.30 a.m.	V	84·0°	

(See also graph 1.) T = In shade of a tree; B = In the barge;
U = Under rest-house verandahs.

Winds.

The winds were extremely variable both from day to day and during each day in direction and force. Until the end of April the winds blew steadily from the N.E. or E.N.E. In May the prevailing winds were S.W. but they varied considerably from W. to S.E., and very occasionally they were from the N.E. In June they were still mainly S.W. but there were more frequent winds from the N., N.E. and N.W. The July and August winds were almost entirely S. or S.W. except during a short spell, 14–19th August, when they were mainly from the N.E. In September they were still mainly S.W., but more frequently N.E., E. or S.E.

3. Climatic Conditions, 1926–28.

The first recorded swarming took place in June 1928, and the meteorological records have been studied in an effort to trace any abnormalities during the period 1926/28 which might have caused or assisted the transition from the solitary to the swarming phase.

Rainfall.

It is considered that unusual early rainfall is most important, since it is presumed that these rains launch the breeding season and therefore regulate both the time and synchronisation of the generations throughout the wet season. Variations in the middle rains are probably of minor importance, unless there is any marked break, and the variations of the late rains are considered still less important, since there is no lack of moisture owing to the rising floods. Any unusual rainfall in the dry season is probably significant, though what its reactions might be is uncertain until the behaviour of *Locusta* during the dry season is known.

The following factors therefore appear to be the most material, (*a*) time of onset of rains, (*b*) rate of onset of rains, (*c*) intensity of early rains, (*d*) intensity of middle rains. Factors (*a*) and (*b*) may conveniently be analysed by using degree of wetness rather than the actual rainfall.

(*a*) *Time of Onset of Rains.*—In Nigeria it was found that the rains had an appreciable effect on the adult locusts when the wetness rose to 2°. By plotting the monthly degrees of wetness and taking each month's figure as representing the 15th of the month, it is possible to indicate when the wetness reached the 2° mark, and so compare one year with another (Table X).

Although no year is very prominent for unusual rainfall, in 1926 the rains set in unusually early in the region San to Douentza, in fact at Bandiagara, Diafarabe, Macina and Douentza, they started earlier than during any other year for which there are records, and at San and Segou only slightly later than the earliest. Mopti was the only exception, and even there the rains were earlier than average. The rains were again early in 1927 in the south, especially at San and Segou. In the north from Niafunke to Kabara the rains were probably earliest in 1924. During no year were the rains generally late.

(*b*) *Rate of Onset of Rains.*—The length of the period, in days, taken by the wetness to rise from 0·5° to 2° may be taken as a rough index (Table XI). It is seen that not only were the southern rains early in 1926, but they also started very suddenly, while the 1927 rains also started quickly. In the north the unusually early rains of 1924 were also characterized by their sudden onset. There can be little doubt that a sudden commencement of the rainy season would tend to cause all the *solitaria* to start breeding at about the same time, and in such a year as 1923, when the rains commenced very spasmodically, the first generation of hoppers would appear irregularly over a long period. It is obvious that synchronisation of breeding favours the development of the swarming phase.

(*c*) *Intensity of Early Rains.*—This is shown in Table XII by the percentage deviation from average of the rainfall during the period April-June. It will be seen that in 1926 as far north as Douentza the rains of this period were well above average, that in 1927 there was a similar though less marked effect, and that in no other year was there such a generally heavy early rainy season.

(*d*) *Intensity of Middle Rains.*—Both years 1926 and 1927 were characterised by peculiarly low July rainfall (Tables VIII, IX). Normally in the south the rains gradually increase from March or April to about August with a single maximum, but in 1926 after the sudden and early onset of the rains there was a lower rainfall in July than in June at six stations and but a slight increase at the others. A similar though again less marked phenomenon occurred in 1927. Otherwise, except at San in 1923 and Macina in 1929, this never happened during the other years for which records are available. This phenomenon did not occur in the north in 1926.

Relative Humidity.

The relative humidity records from the following stations have been examined in detail but no abnormalities during the years 1926 to 1928 have been discovered :—Bamako 1924–1932, Nienebale 1923–1932, Mopti 1925–1932, Kabara 1923–1932.

4. Ecoclimates.

No detailed study was made of the ecoclimates within the different plant associations, but the following few observations indicate how the temperature and especially the relative humidity varied in the different environments. The Seyna observations, where the two sets of readings were taken within 30 yards of each other, are especially interesting. The temperatures were taken with a whirling hygrometer, one foot above ground-level in the shade of the observer.

Mopti.—Comparison of a shallow valley, about 10 ft. deep and 25 yds. wide, with *Cyperus* sp. about 2ft. 6ins. high, and the top of the bank at the edge of the Borghu plain sparsely strewn with straw of dead grasses.

	11th June, 8 a.m.		*3rd July, 7 a.m.*	
	Dry Bulb. Degrees	*Rel. Hum.* Per cent.	*Dry Bulb.* Degrees	*Rel. Hum.* Per cent.
Valley	87·3	51	82·2	53
Bank	87·8	48	82·8	50

Benenigeni.—Comparison of a belt of green *Vetiveria* about 1½ ft. high and a belt of low burnt *Andropogon* with fresh growth about 9 ins. high.

	20th June, 7 a.m.	
	Dry Bulb. Degrees	*Rel. Hum.* Per cent.
Vetiveria	78·9	60
Andropogon	81·0	58

San.—Comparison of shallow dry stream-bed, about 10 ft. deep and 20 yds. wide, with scattered tall *Cyperus* sp. and *Mimosa* bushes, and the top of the bank at the edge of the plain covered with a fairly dense stand of mixed fresh grasses 3 ft. high.

	20th June, 7.40 a.m.	
	Dry Bulb. Degrees	*Rel. Hum.* Per cent.
Valley	82·8	65·5
Bank	83·8	61·0

Seyna.—Comparison between open burnt plain and dense stand of dry *Andropogon gayanus* about 6 ft. high.

	29th June, 10.0 a.m.	
	Dry Bulb. Degrees	*Rel. Hum.* Per cent.
Plain	89·0	54
Dense grasses	98·9	39

The above differences in the relative humidity probably explain the very distinct preference shown by *Locusta*, both *solitaria* and *gregaria*, for the valleys and depressions. At Seyna the locusts were much more abundant in the open plain and were not apparently attracted to the dense *Andropogon*, which would have given excellent protection but in which the ecoclimate was unfavourable. These observations were taken in the morning and the differences are probably more marked later in the day.

IV. Vegetation.

1. Major Divisions.

Chevalier (2, etc.) has described the geobotanical divisions of North-west Africa. He divides the area into three natural regions or belts lying parallel to the Equator. Each is divided into two zones and the zones are subdivided into provinces.

The whole of the area surveyed lies in the Sudanese region and all except the extreme south in the Atlantic-Niger province of the " Steppes Saheliennes " or thorn country zone, and the southern parts in the middle Niger and West Upper Volta province of the Sudanese or transition from parkland to grassland zone. These two zones are demarcated, according to Chevalier, by the nature of the herbaceous ground covering during the rains and the consequent severity of the dry season bush fires. In the Steppes the ground covering is open and the bush fires are neither violent nor extensive, while in the Sudanese zone the ground is completely closed with dense and frequently tall herbaceous growth and the bush fires are necessarily extremely intense. This classification of the vegetation, however, really applies more to the surrounding country than to the inundated area itself, where the river system is the primal factor affecting the plant ecology and where the vegetation is very largely an expression of the physiographic features of the great river valley.

2. General Classification—Zonation and Phases.

In the inundated area there exists a marked and regular zonation with plant communities of similar life form recurring in the same order as one moves away from the river-bed. The floristic compositions of these zones naturally vary somewhat between the southern and northern limits, but on the whole they are fairly constant and in each particular district they are normally identical. This climax zonation follows all the land contours and is presumably due primarily to the increasing depth of the water-table as the ground rises away from the river-bed. Throughout the inundation area the altitudinal variation, excluding outcrops, is only a matter of a few feet but is sufficient to produce a number of communities of very different life forms.

Before this zonation is discussed it is necessary to emphasise that the study of the zonation is complicated by the series of annual phases through which the vegetation passes with the seasons. There are two extreme phases, the xerophytic and the marshland (Plate III, figs. 1 and 2). In the xerophytic the flood water has retreated and the rains have not commenced sufficiently to moisten the soil, consequently most of the grasses have dried off and have usually been burnt to the ground, giving place to a different type of vegetation with carpet-herbs dominant. During the marshland phase the soil is well moistened, if not flooded, by the combined effect of rainfall and river flood and the grasses are fully developed and in flower, while the lower herbs are normally completely submerged. It would appear that any detailed study of the vegetation in the middle Niger valley should be made on the lines detailed by Saxton (11) in his study of vegetation under monsoon conditions in India.

During the present survey it was impossible to study the annual cycle of these phases in each district. Along the Niger from Segou to Timbuctoo they do not coincide owing to the different times of maximum rainfall and flood. Thus, throughout the journey to Timbuctoo observations were taken in all districts towards the end of the xerophytic phase, while the marshland phase was only studied at Mopti and Diafarabe on the return journey. Under these conditions identification of the vegetation was extremely difficult. During the xerophytic phase the zonation was very distinct but the absence of flowers prevented identification of the grasses. During the marshland phase the zonation was almost and sometimes completely masked by the dense growth of a large number of species, and it was usually impossible to allocate the species to the dry season zones, which have therefore to be given an arbitrary nomenclature. It will be realised that this luxurious herbaceous growth in the inundated area encourages such violent bush fires that normally only occur south of the Sudanese region.

The following summary of the main types of vegetation encountered indicates the general sequence of the vegetation zones from the river-bed to the parkland, during the xerophytic phase. The zones occur in parallel strips sometimes only a few feet and sometimes several miles wide. The inundated area does not usually extend above zone 3a and therefore the zones 3b–4c do not pass through any marshland phase.

3. Index to Main Vegetational Types.

1. STRAND.

Vegetation growing along the main water-courses.

(*a*) *Water's edge.*

A growth of succulent herbs and grasses, normally dense, about ½ to 2 ft. high, sometimes submerged, at the water's edge ; mostly flowering in May. This vegetation is normally restricted to backwaters and is not much in evidence along the actual river's edge.

(*b*) *Low sandhills in main channels.*

Very scattered single tufts of herbs or grasses about 9 ins. high mainly occurring in slight depressions close to small pools.

(*c*) *High sandhills and alluvial cliffs on main channels.*

(i) Lower levels, with sparse covering of low herbs and grasses ; (ii) upper levels, with low bushes of *Mimosa, Zizyphus, Sesbania*, etc.

2. GRASSLAND.

(*a*) *Depressions and hollows.*

Here and there throughout the grass plains deep depressions occur and these may or may not retain water through the dry season.

(i) Perpetual swamps (probably springs), in which (*a*) the lowest lands are covered with a dense matted growth of short succulent vegetation about 1 ft. high, and these are frequently surrounded by (*b*) a zone of tall grasses and herbs which dry off in the dry season.

(ii) Dried swamps or pans, consisting of (*a*) baked, fissured clay, often with a fine deposit of salt, and with only a very sparse vegetation of rosette herbs on the lowest lands (there may be open water in the centre of the pans) ; and above this level comes (*b*) a zone of short turf-forming grasses and sedges which remain green. After this follow two zones corresponding to 1 (*c*) (i) and (ii).

(*b*) *Lower clay levels.*

These cover the major part of the vast inundated plains, and trees and shrubs are completely absent. They comprise :

(i) *Cyperus* associations: The lowest lands, small depressions, etc., invariably support an almost pure stand of tall succulent *Cyperus* spp (*dukon* in Bambara), growing in dense clumps about 2 ft. high which usually escapes the fires and remains green except in the extreme north.

(ii) Low bushes : As 1 (*c*) (ii).

(iii) Borghu plain (Plate IV, fig. 2) : Throughout the centre of the inundated area this is the main plain level and is covered during the xerophytic phase with recumbent dried-up remains of tall grasses with very new growth appearing during the early part of the rains. The dominant grasses are probably *Panicum Burgu, P. pyramidale* and *Leptochloa caerulescens*. During the xerophytic phase this zone is clearly divided into two levels, but during the marshland phase it was impossible to identify any of the grasses collected with either and consequently the native names are used :—(*a*) *Gamawa :* the ground is covered with very low tufts from which the new growth appears during the early rains ; (*b*) *Didere* (Plate IV, fig. 2) : here there are no tufts and the new shoots are evenly but sparsely distributed over the surface and dry straw is much more abundant, this being the typical Borghu level.

(iv) *Vetiveria* association : Throughout the Borghu plain any slight ridge is marked with the distinctive dense clumps of *Vetiveria nigritana* (*babin* in Bambara) which are frequently three feet high. Like the *Cyperus* this grass remains green throughout the year and normally escapes complete destruction by bush fires. The density of the plants in this association varies considerably and it is convenient to divide it into (*a*) dense *Vetiveria*, (*b*) open *Vetiveria* (Plate V, figs. 1 & 2).

(*c*) *Transition from grassland to parkland.*

(i) Lower levels: Where lighter soils overlie the heavy clays the character of the grassland changes very considerably, the evergreen *Vetiveria* association giving place to stands of grasses that dry out completely in the dry season and which are therefore very susceptible to bush fires, though occasional areas escape destruction. These normally grow to a height of 3 to 5 feet. Very occasional bushes, especially *Bauhinia reticulata*, and trees, especially *Mitragyne africana*, occur and their rarity is probably largely due to human agency.

(ii) Upper levels: Any light sandy soil ridges are clearly marked with a dense growth of grasses, especially *Andropogon gayanus* (*zara* in Bambara) and *Cymbopogon giganteus* growing to a height of perhaps 10 feet. These also dry out completely in the dry season.

3. PARKLAND.

(*a*) *High grass and low tree savanna.*

This vegetational type only occurs towards the south, *e.g.*, between Bamako and Segou. The coarse grasses are 5–12 ft. high during the rains and there are bushes and small trees forming open parkland. In the dry season the ground covering is normally completely burnt.

(*b*) *Acacia and tall grass savanna.*

This and (*c*) are the commonest types of parkland fringing the marsh grass plains. There are a number of scattered trees and a continuous ground covering of herbs and grasses 3 to 6 ft. high, which, although they dry out completely in the dry season frequently escape the fires.

(*c*) *Acacia and desert grass savanna.*

This is similar to (*b*) but occurs further north and the ground covering consists of sparse short grasses that are rarely burnt.

(*d*) *Dry forest.*

This is a variation of (*c*) with the trees predominating over the grasses.

(*e*) *Thorn thickets.*

Occasionally the above types of parkland give place to local areas of impenetrable thorn thickets. They also occur on raised islands within the grassland.

(*f*) *Palm stands.*

(i) *Borassus*: Towards the south stands of these palms, *Borassus flabellifer* var. *aethiopum*, are very common on occasional hillocks and especially on the village islands.

(ii) *Hyphaene*: Towards the north the *Borassus* is replaced by the Dum palm, *Hyphaene thebaica* var. *occidentalis*, which is dominant on all the long sand-dunes that alternate with the grassland plains in this area. The ground between the palms is very open with a short growth of low herbs and grasses.

4. DESERT.

This type of vegetation occurs in the extreme north.

(*a*) *Valleys.*

Between the dunes in the neighbourhood of Timbuctoo frequent shallow valleys occur with a fairly closed short ground covering of herbs and grasses.

(*b*) *Desert shrub and dessert grass.*

(i) Sand-dunes: North of Timbuctoo the dunes are well covered with low xerophytic thorny shrubs and bunch grasses.

(ii) Scree: This type of vegetation was seen only on the hillside by Lake Horo; *Commiphora* and *Euphorbia*, about 20 ft. high, form a fairly dense scrub with tufted grasses about 1½ ft. high growing between the stones.

4. Vegetational Description of Localities.

Bamako to Segou (April and September).

This area was only traversed rapidly by road. The country is hilly with typical high grass and low tree savanna and occasional glades of open grassland. In April the herbaceous ground-covering had been almost destroyed by fire, and in September it was very dense and grew to a height of 6–10 ft. The banks of the Niger in this reach were not examined, but it is believed that there are only occasional narrow strips of open grass along the banks.

Segou to Macina (April).

This reach of the river was not studied in detail. *Xerophytic phase*:—1. *Strand*: as at Macina; 2. *Grassland*: above the low bush level normally only a belt of *Andropogon*, 2 (*c*) (ii),* a few yards wide, usually no extensive grassland; 3. *Parkland*: acacia and tall grass savanna, 3 (*b*), with occasional thorn thickets.

Marshland phase:—1. *Strand*: totally submerged; 2. *Grassland*: ground submerged with tops of tall grasses forming a closed cover over the water surface; 3. *Parkland*: 3 (*b*), ground submerged with grasses rising above the water, trees rather dense.

Macina (May).

Xerophytic phase:—

1. *Strand*: (*a*) Normally absent but the following plants were identified from one typical association:—*Grangea maderaspatana*, *Stachytarpheta angustifolia*, *Heliotropium indicum*, *Cyperus radiatus*, *Cyperus maculatus*, and *Scoparia dulcis*.

(*b*) Typical very sparse short tufts, with *Mollugo Cerviana*, *Fimbristylis Cioniana* (abundant), and *Eragrostis cilianensis*.

(*c*) (i) Typical low sparse ground covering, *Cynodon Dactylon* and *Glinus lotoides*; (ii) bushes usually 3 to 5 ft. high, dense: *Mimosa asperata*, *Sesbania aegyptiaca* and *Salix Ledermannii* (this was not associated with the first two but occurred at a similar level).

2. *Grassland*:

(*a*) (i) Absent; (ii) There were no dried swamps near Macina corresponding to this level elsewhere, but the banks of some of the stream-beds which still held water in May appeared to correspond with level 2 (*a*) (ii) (*b*) and were covered with very short turf sedges, probably mainly *Cyperus maculatus*. A narrow belt of trees, *Syzygium guineense*, separated this zone from the main grassland levels.

(*b*) (i) Depressions are not common in this district, but where they occur they were clearly marked with a dense *Cyperus* growing to a height of about 2 ft., which was not determined but was probably *C. auricomus*. Some of the depressions fell below the *Cyperus* level leaving bare fissured clay. These areas were still green at the end of the dry season; (ii) Normally absent; (iii) This zone was absent owing presumably to the steep incline from levels (*b*) (i) to (*b*) (iv); (iv) Typical *Vetiveria* associations were very restricted in area and number, occurring along the first raised bank of the river (Plate V, fig. 1) and round the *Cyperus* depressions. They were clearly divided into two belts, the lower (*a*) quite fresh and about 2 ft. high, and the upper (*b*) burnt down to a height of 6 to 9 ins.

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* Such indications refer to the preceding Index to Main Vegetational Types.

(*c*) (i) Most of the open spaces, which occasionally extended over an area ½ mile square, were covered with this association, but the grasses were very mixed and it was impossible to determine the floristic composition. The grasses were open and very irregular in height. (ii) Several ridges were well marked by this distinctive association, which in spite of its dryness had escaped the fires in many places.

2. *Parkland :*

(*b*) This was really the dominant level in the Macina district. Most of the parkland is Acacia and tall grass savanna, with *Bauhinia reticulata* and *Mitragyne africana* common.

(*c*) Absent.

(*d*) Within the parkland there were occasional areas of closed *Acacia* woodland.

Macina-Suli-Sarro-Funa (May).

Xerophytic phase :—

Large expanses of undulating grassland, 2 (*c*) (i) and (ii), with a few pools still remaining near the Niger, intersected by winding dried-up stream-beds, along which frequently grow the tree, *Syzygium guineense*, and which were lined with either turf grasses, *Cyperus* or *Vetiveria*, according to their depth.

Further inland typical savanna, 3 (*b*), with tall dry grass in tufts, changing to dense thorn in places. Other areas with low bushes (*Geira senegalensis*) and no herbaceous carpet. Occasional large stands of *Borassus* and very occasional *Hyphaene*. Only one grass was identified, *i.e.*, *Eragrostis gangetica*, growing in separate tufts about 1½ to 2 ft. high in the more open areas.

The following other trees were identified :—3 (*b*). *Bauhinia reticulata*, abundant, *Mitragyne africana*, abundant, *Combretum micranthus*, *Balanites aegyptiaca*, common, *Khaya senegalensis*, in groups, *Pseudocedrela Kotschyi*, in groups, *Acacia albida*, occasional, and *Butyrospermum parkii*, occasional ; 3 (*e*), *Acacia albida*, *A. seyal*, in dense thickets, *A. senegal*, *Tamarindus indica*, *Ximenia americana*, *Zizyphus jujuba*, and *Balanites aegyptiaca*.

In places the savanna opens out with extensive tracts, several miles wide, of open grassland, 2 (*c*) (i). Although this grass was tinder dry in early May very little had yet been burnt, and the natives informed me that only those areas to be cultivated are burnt intentionally just before the land is broken up. It was usually very dense and up to about 8 ft. high.

In places this land was being tilled for rice cultivation, and in the middle of one of these areas a swamp with open water was examined. It was surrounded by tall tangled *Cyperus* and above that *Vetiveria* in association with *Scirpus corymbosus*.

Marshland phase :—

This area south of the Niger was not revisited during high water, but I was informed that the whole of the land excluding the islands and ridges is submerged at least as far south as Suli and Sarro.

Macina to Diafarabe (May).

The vegetation of this area was not surveyed in detail but it appeared very similar to that further upstream. The dominant type is Acacia and tall grass savanna with local areas of thorn. The important transition to open grassland occurs some seven miles west of Diafarabe especially on the north bank. This grassland was similar to that described below.

Diafarabe (May–June and September).

This was the area studied in most detail and the following is a description of the general lay-out.

Xerophytic phase, as at Macina :—

South Bank.—Only a narrow strip of grassland, a few hundred yards wide, mainly (*c*) (i), with tall *Cyperus* in the many channels parallel to the river. *Zizyphus*, *Mimosa*, and occasional *Eugenia* occurred along the banks ; then the dominant Acacia and tall grass savanna, which extended as far as was traversed and which probably extends to the River Bani. Within the savanna occurred occasional large areas of (*c*) (i) grassland, but no *Vetiveria*, with dense thorn thickets on the islands.

North bank, east of River Diaka.—The town of Diafarabe occupies the south-west corner of this area and is surrounded by farmland within the old irrigation canals of the deserted agricultural station. A small village, Dar-es-Salaam, lies about ¾ mile down the Niger. An extensive grass plain extends for about 5 miles to the north-east. The dominant level was open *Vetiveria* (Plate V, fig. 2) ; there were practically no deep hollows, but even the slight depressions carried the typical *Cyperus* association. The plain gradually merged into typical savanna, but the trees were much more scattered than on the south bank or further upstream.

North bank, west of River Diaka.—This area was very similar to that across the Diaka and the grassland extended for about the same distance. It was broken by a number of thorn-thicket islands. Some five miles inland one swamp of type 2 (*a*) (ii) (*a*) with some water in the centre was encountered.

Raunde Island.—This small island, about one mile long, lies off the town of Diafarabe. It is mainly grassland but shows the complete zonation from the lowest bare levels to parkland.

The following plants have been identified :—

1 (*a*) As at Macina, but *Cyperus maculatus* especially abundant and frequently forming a strip of turf along the water's edge.

1 (*c*) (ii) *Mimosa asperata* and *Zizyphus* sp.

2 (*a*) (ii) (*b*) *Cyperus maculatus* occurred again here forming quite extensive areas of turf ; (*c*) *Grangea maderaspatana*, normally dominant, *Polygonum plebeium* and *Polygonum limbatum.*

2 (*b*) (i) *Cyperus auricomus*, dominant, and *Polygonum senegalense* ; (iv) *Vetiveria nigritana*, dominant, in large, well-separated, raised tufts, and *Sorghum trichopus* (marshland phase).

Marshland phase :—

In September, at high water, the whole of the area, excluding the islands, was flooded (Plate III, fig. 2). The *Vetiveria* level was under about 1½ ft. of water with the top of the grass 3 to 5 ft. above water-level. The flood extended well into the parkland but at its edge was only 6–9 ins. deep with the assorted grasses again well above the surface.

The following plants were collected during high water from the inundated grassland but it was impossible to assign them to any particular level :—*Eragrostis gangetica*, *Panicum longijubatum*, *Paspalum scrobiculatum*, var. *Commersonii*, *Cyperus procerus*, *Polygonum lanigerum*, *Aeschynomene aspera*, very common, and *Andropogon canaliculatus*, rare ; 3 (*a*) *Mitragyne africana* and *Bauhinia reticulata.*

Analysis of Vetiveria *habitat* :—

Owing to the apparent importance of the *Vetiveria* association this was studied along a belt transect 1 mile long and 3 ft. wide running north-east from a little way north of Dar-es-Salaam on 29th May. Table XVII gives details of the distribution and size of the *Vetiveria* tufts in each quarter mile of the transect.

TABLE XVII.

Vetiveria *Association, Dar-es-Salaam.*

Quarter-mile section of transect	No. of tufts per chain	Height of tufts (ins.)			Diam. of tufts at base (ins.)			Ground covering. Per cent.
		Average	Max.	Min.	Average	Max.	Min.	
1	5·4	17	27	9	8·9	14	2	1·1
2	15·8	17	38	6	10·7	40	1	4·7
3	14·3	20	72	6	9·6	24	2	3·5
4	18·1	20	84	3	10·5	40	2	5·2

The following notes on *Vetiveria nigritana* are taken from Chevalier (³) :—

" Perennial in large tufts ; roots odoriferous, leaves green throughout the year. Stems 1 to 1½ metres high, terminating in panicles 20 to 30 cm. long. Grows in large tufts in the low ground which is inundated in the wet season and which remains slightly moist almost throughout the year ; especially abundant in the depressions close to the rivers in the Soudanese zone ; there the tufts form innumerable clods raised some 20–30 cm. above the soil. After the dry season when there is no other green forage new leaves are grown. At this time the horses and cattle feed on the foliage and even relish it though they avoid it in the wet season. In the dry season the nomads lead their flocks to the depressions where this plant abounds."

Diafarabe to Miyatiki (May).

This stretch of the River Diaka was similar to the main Niger channel. After passing through the Diafarabe grass plain the river penetrates typical parkland and then towards Miyatiki occasional high sand-hills occur along the banks while the surrounding country descends to the Borghu level.

Miyatiki-Tenenkou (May and September).

Miyatiki was visited at the end of May and Tenenkou in September. Briefly the main zonation at Miyatiki is as follows : a narrow belt of open *Vetiveria* along the raised banks of the river, then the lower extensive Borghu plain of mixed *gamawa* and *didere* with occasional perpetual swamps, 2 (*a*) (i), surrounded by dense matted fresh vegetation about 6 ins. high with *Jussiaea villosa* abundant and water-lilies in the open water. There are also extensive clay pans, 2 (*a*) (ii), with a small leguminous herb very scattered over the surface. Some 2 to 5 miles away from the river the land rises and the Borghu plain gives place to open *Vetiveria* before the commencement of the parkland, which was not visited. The sand-hills were mainly bare with a few stunted *Hyphaene*, many *Calotropis procera*, and a tall unidentified *Euphorbia. Fimbristylis Cioniana*, *Cyperus maculatus*, *Grangea maderaspatana*, *Salix Ledermannii*, *Mimosa asperata*, *Zizyphus*, and *Andropogon gayanus*, all occurred at the usual levels. There were many *Borassus* palms on the village islands, each of which was surrounded by a *Vetiveria* belt.

Tenenkou lies about 4 miles north-west of the river on a sandy ridge. When this village was visited the barge was able to proceed straight over the Borghu plain, which was under several feet of water with the tops of the grasses 1 to 2 ft. above the surface. This area was not examined and only the following plants were collected from the inundated grassland—*Saccolepis interrupta*, *Eleocharis plantaginea* and *Scirpus corymbosus*.

Diafarabe to Mopti (June).

The main vegetation of this stretch was of the parkland type previously only seen close to the river west of Macina, normally without any *Vetiveria* belt along the banks and only occasional tufts in the hollows. The trees were mainly *Mitragyne, Bauhinia, Balanites* and *Acacia.*

Mopti (June, July and August, September).

The vegetation was essentially the same as at Miyatiki.

Xerophytic phase :—

South bank.—The main plain level was Borghu with mixed *gamawa* and *didere*, which extended for about 7 miles away from the river and was only broken here and there by slight ridges covered with *Vetiveria* or depressions with *Cyperus*, open clay or standing water (Plate IV, fig. 2). As usual there were occasional islands with thorn thickets while others have larger trees, *e.g., Tamarindus.* After the Borghu came a belt of *Vetiveria* about 3 miles wide before the parkland. The following plants were identified :—1 (*a*), *Cyperus Baikiei* and *C. radiatus* ; 2 (a) (ii) (*a*), *Heliotropium Baclei* and *Striga Forbesii* ; *b* (iv), *Eragrostis gangetica*, in small separated tufts about 2 ft. high amongst *Vetiveria.*

North bank.—Only the promontory between the converging Rivers Niger and Bani was examined. As on Raunde Island at Diafarabe this small area showed the full zonation in a marked manner owing to the undulating nature of the ground. A dense, tall, green *Cyperus* association filled the centres of the valleys unless they were especially deep, when only bare clay was found. Above the *Cyperus* came scattered bushes of *Zizyphus spina-christi* and *Mimosa*, then the Borghu level, 2 (*b*) (iii) (*a*), followed by open *Vetiveria.* Above the *Vetiveria* most of the ridges were covered with Borghu, 2 (*b*) (iii) (*b*), and in this respect the zonation differed from the normal, since the *Vetiveria* usually lies above all the Borghu. The intermediate *Vetiveria* was never abundant and sometimes it was absent. High islands were covered by dense thickets and the main area to the west by typical parkland.

Marshland phase :—

At the end of August and in early September the whole of the area surrounding Mopti, excluding the islands, was submerged, but ill-health prevented observations from being taken.

The following grasses were collected from the main inundated grassland, each rising some 3 ft. above the water surface ; *Echinochloa stagnina*, *Panicum longijubatum* and *Eragrostis gangetica.* The panicles of *Vetiveria* were some 8–9 ft. above the surface. Above the *Vetiveria* level at the edge of the wooded islands the following two grasses were taken—*Setaria sphacelata* and *Echinochloa pyramidalis.*

Fotoma (July).

This village, where hoppers were reported in 1928, was visited early in July. It lies on the edge of the parkland 11 miles north-east of Mopti. The only area that appeared of interest was the narrow shallow valley of a small river that descends from Bandiagara and enters the Niger midway between Mopti and Konna. Although there was a fair amount of water in this river at Bandiagara the valley at Fotoma was dry. Running through the fairly dense parkland and farmland there was a strip of dense *Vetiveria* grassland about 500 yards wide with quite a number of trees, mainly *Mitragyne.*

San (June).

The town stands on a distinct red-sand ridge and was surrounded mainly by farmland and *Geira-Andropogon* scrubland. The commonest tree was *Butyrospermum Parkii.* The only interesting locality, so far as *Locusta* is concerned, was the wide, shallow, open, grassland valley running north to south-east of the town. This valley is about 4 miles wide between San and the village Teneni and, according to the maps, extends about 45 miles from the Bani southwards. This is another area from which hoppers were reported in 1928. The main level appeared to be interzonal with a mixture of *Vetiveria* and the grasses of level 2 (*c*) (i) and a certain amount of short *Cyperus* sp., all of which were green. The *Vetiveria* decreased towards the edge of the valley. *Portulaca foliosa* was fairly common, growing under the occasional trees. Through the valley there is a narrow, deep, meandering dry water-course with typical high *Cyperus*, *Mimosa* and *Zizyphus* levels.

Benenigeni (June).

This is the village on the Bani which serves as the port for San. On the north bank the parkland was fairly dense and was probably mainly high grass and low tree savanna. On the south bank the high ridges were covered with *Butyrospermum-Geira-Andropogon* scrub. East of the village there are a number of small valleys running parallel with the river exhibiting the usual zonation from tall *Cyperus* to dry grass. In June the vegetation was growing rapidly following the first rains and a *Cyperus*, probably *C. sphacelatus*, was growing up between the *Vetiveria* tufts.

Seyna (June).

A brief halt was made here at the end of June to examine the north bank. Above the usual river-bank levels the river was bordered by a thin belt of *Acacia* and tall grass savanna, then a narrow dense belt of *Andropogon gayanus*. After this the ground falls and there was a broad open *Vetiveria* plain some 3 miles wide before reaching low sandy ridges with dry *Andropogon*. There were the usual occasional thorn-thicket islands and depressions going down to the Borghu, some only to *didere* others to *gamawa*, with *Mimosa* bushes between.

River Bani, Benenigeni to Mopti (June).

Along most of this stretch the Bani runs through well wooded country which at times forms a closed canopy. The only extensive *Vetiveria* grassland was that near Seyna but elsewhere there was open, dry *Andropogon gayanus*. The following three herbs were taken in level 1 (*c*) (i)—*Polycarpaea linearifolia*, *Heliotropium strigosum* and *H. ovalifolium*, in association with the grass *Digitaria aristulata*, growing in small tufts.

Mopti to Bandiagara (July).

After leaving the Mopti grassland the road gradually ascends the Bandiagara hills, passing first through *Acacia* and tall grass and then open woodland. On the hilltops the vegetation was mainly bush scrub, 8 to 9 feet high, with a very open dry-grass ground-covering about 1½ feet high. The bushes included *Bauhinia reticulata*, *Balanites aegyptiaca* and *Combretum* sp. Around Bandiagara large trees are common, especially *Adansonia digitata* and *Tamarindus indica*, and there were also many bushes of *Geira senegalense*. In occasional narrow stream-beds scattered *Vetiveria* tufts occurred.

Konna (July).

Only a brief call was made at this village. On the western bank of the Niger, after a few wide belts of *Vetiveria* with Borghu interzones the main plain descends to the Borghu *didere* level. This extends westwards to the horizon and was only broken by occasional large areas of standing water.

On the east bank the Borghu zone was only about ½ mile wide. It was followed by a bare sandy zone with no grasses and a few low herbs, especially *Grangea maderaspatana*, and a number of large boulders. There was then a slight sandy ridge with cotton farms and many *Tamarindus* trees. Beyond, the ground sloped down to another open sandy plain with a few *Tamarindus* and scattered bushes of *Zizyphus*, *Balanites* and an undetermined Asclepiad. In this plain there are occasional large depressions with typical dense *Vetiveria*. Further east dry forest with little or no grass-covering, with *Geira* bushes in more open places, stretched towards the hills. It was noted that this appears to be the northern limit of the *Borassus* palm and therefore the commencement of the Sahelian zone.

River Niger, Mopti to the Koli-Koli (July).

Throughout this stretch of the river the country becomes more and more open and mostly appeared to be typical Borghu plain, which was always more extensive on the west bank. The grass, *Hemarthria fasciculata*, was taken amongst the short *Cyperus* of zone 1 (*c*) (i).

River Koli-Koli (July).

The grass *Leptochloa caerulescens* was abundant along the bottom of the steep clay river-bank in zone 1 (*c*) (i). On the north-west bank the vegetation remained much the same, *i.e.* mainly Borghu, but there were quite a lot of *Vetiveria* zones. Swamps and small lakes were more and more numerous. To the south-east the hills come within a mile of the river and there was little open grassland. The whole country flattens out towards Lake Korienze. The lake is about 10 miles long and perhaps 5 miles broad, being surrounded by a Borghu *didere* plain with tall *Cyperus* at the water's edge. The surrounding low sandy hills were covered with orchard or bush scrub including *Bauhinia* (?) *rufescens* and *Balanites*. A small Liliaceous plant was common but grasses were scarce. By 20th July the water had risen above the *Cyperus* level and was spreading across the Borghu, which was growing rapidly as it became submerged.

Korienze (July).

This town lies on a sandy ridge on the eastern shore at the northern end of the lake.

East Shore.—There was an extensive fore-shore $\frac{3}{4}$ mile wide corresponding to level 1 (*c*) (i) with many small prostrate herbs, mainly *Heliotropium Baclei* and *Herderia truncata*, but no grass. At the water's edge there was a narrow strip of short *Cyperus*. Towards the grassland the shrub, *Borreria verticillata*, 2 to 3 feet high, was abundant, and there were stretches of *Cynodon dactylon* and occasional tufts of *Vetiveria* and dry *Andropogon*. Above the fore-shore low clumps of *Hyphaene*, bushes of the unidentified Asclepiad, *Calotropis procera* and *Euphorbia* were scattered over the lower levels of the sandy ridge. There was practically no herbaceous ground-covering. The top of the ridge was undulating red sand with *Geira senegalense* dominant, many clumps of low *Hyphaene*, *Balanites* (common) and some *Euphorbia*. The eastern slope of this ridge was well cultivated. Below was open dry grassland with a large belt of *Vetiveria* followed by a narrow strip of Borghu *didere* and open mud round the pool Kogi. The transition from dry grass to *Vetiveria* corresponded with the change from sand to clay.

West Shore.—Here the foreshore (2 to 3 miles wide) was typical Borghu with rather open *Vetiveria* on any slight rise while around was a belt of *Vetiveria* followed by a belt of the shrub *Borreria verticillata*. Behind were undulating high sandhills with a great number of *Hyphaene* and some *Euphorbia*.

Rocher Marie Therese, Lake Debo (July).

The route taken from Lake Korienze to Lake Debo followed one of the many channels that form a network of waterways through the Borghu plain in this part. Rocher Marie Therese rises 230 feet from the plain. It was covered with dry grass and bushes between the rocks. All the surrounding land from the south-east to the south-west was Borghu plain (Plate IV, fig. 1.). Lake Debo lies to the west with the eastern shore well defined by a broad belt of sandhills with *Hyphaene* and *Euphorbia* abundant. Behind lay farms—rice, maize, millet and cotton. To the north-east there was an extensive *Vetiveria* plain, which had been well burnt, with

Acacia thickets further inland. The shore of Debo was mainly short *Cyperus*, similar to level 2 (*a*) (ii) *b*, with occasional areas of *Vetiveria*, especially north of the Bara-Issa outlet.

River Bara-Issa (July).

This river was mainly bordered by sloping banks of Borghu *gamawa* with a belt of *Vetiveria* along the top, then *Acacia* savanna, mainly tall grass. Towards Sarafere the soil is much more sandy and the orchard came close to the water with no intermediate grass zone. High sandhills covered with dense *Hyphaene* became frequent.

Sarafere (July).

The town of Sarafere stands on a sandy ridge running west to east at right angles to the Bara-Issa, between two wide shallow valleys. In the southern valley there was a narrow level of Borghu *gamawa* along the stream, then a wide belt of Borghu *didere* bordered by a typical wide dense *Vetiveria* zone. To the south this merged into *Acacia* savanna and to the north, towards Sarafere, there was a stretch of old farmland with frequent tufts of *Andropogon gayanus* and *Eragrostis albida*, and a ground-covering of *Cynodon dactylon* below the sandhills. These carried the usual *Hyphaene* clumps with straggling tufts of *Aristida pallida* in the intervening spaces and much *Ipomoea* sp. on the lower levels.

The northern valley was mainly typical Borghu with mixed *gamawa* and *didere* and with very little *Vetiveria*. One small swamp of type 2 (*a*) (i) was examined and this contained a low tangled mass of sedges including *Cyperus haspan*, *C. nudicaulis*, *Scirpus cubensis* and *Fimbristylis diphylla*. On the western bank of the Bara-Issa a similar alternation of *Hyphaene* sand ridges and Borghu or *Vetiveria* plains occurred.

Lake Horo (August).

This large lake lies north of the Issa-Ber branch of the Niger towards Lake Faguibine. The eastern shore was briefly surveyed. The entrance to the lake at the south was marked by an extensive *Vetiveria* level. This zone was being submerged on 20th August and the water had risen to the tops of some of the tufts. North of the village Gidigada there is a sandy shore in places, and elsewhere the lake was rising over carpet herbs with scattered *Vetiveria*. Above the shore proper there was a sandy stretch about ½ mile wide with *Hyphaene* and various scattered tufted grasses including *Cymbopogon proximus*. Above this a high hill covered with loose scree lies parallel to the shore. Tall bushes of *Commiphora africanum* and *Euphorbia balsamifera* were evenly distributed over the hillside, and between the loose stones there were tufts of various small grasses including *Aristida funiculata*, *A. adscensionis* and *A. papposa*. This hillside was described by Chevalier in 1900.

El Oualadji (August).

The only area examined here was the north bank. This is undulating dune country with *Acacia* and desert grass savanna and occasional *Vetiveria* patches in the hollows.

Dire (August).

The north bank only was surveyed and attention was focussed on the small swamp Hemgu, a mile or so south-west from the rest-house. There was open water in the centre with a dense growth of grasses and dry sedges or farmland all round. The lowest level was occupied by dense *Cyperus* followed by a dense growth, about 2 feet high, of *Panicum repens*, followed by a zone of dense, dry *Scirpus maritimus*. Two low prostrate grasses were common on old farmland, along paths, etc.—*Cenchrus barbatus* and *Echinochloa colonum*. The surrounding country is desert-like with lower silico-argillaceous levels and high bare sand-dunes. *Hyphaene* palms were common and all grasses were very scarce.

Dire to Kabara (August).

Further to the north-east the general level of the surrounding country falls somewhat, with the sand-dunes decreasing and open grass plains much more extensive. Two such areas were visited. The first at Bouramodire, a little way up the stream that flows from Goundam, showed the typical zonation with the main level Borghu and considerable patches of *Vetiveria* on the ridges. At the second, between the villages of Koiretago and Korioume, the river was bordered by Borghu with *Cynodon dactylon* above and a belt of open *Vetiveria* along the top of the bank. Inland there was an immense Borghu plain with some *Andropogon gayanus* and *C. dactylon* on the ridges and an unidentified dead *Cyperus* in the hollows.

Kabara (August).

Again only the north bank was examined. The Borghu plain continued to be extensive past Korioume to beyond Kabara. At Kabara the ground is undulating so that there were considerable belts of *Vetiveria* alternating with Borghu, while there were also extensive *C. dactylon* associations. On other ridges above the *Vetiveria* were tufts of *Eragrostis albida* and *E. pallescens*, with the well-known *Acacia* forest of Kabara stretching to Timbuctoo.

Timbuctoo (August).

The vegetation of this area has been described by Chevalier (18). South of the city lies the dry forest of Kabara which consists mostly of *Acacia* spp., probably mainly *A. tortilis*, with *Balanites* common, on the undulating sandhills. The herbaceous ground-covering was very sparse, but the following grasses were collected—*Aristida mutabilis*, *Brachiaria* sp. aff. *regularis*, *Chloris Prieurii*, *Eragrostis* sp., *Tragus Bertersonianus*, and the sedge *Fimbristylis exilis*.

Northwards there are no trees and desert shrub and desert grass occurred over the dunes. Between the bushes were tufts of mixed grasses, *i.e.*, *Panicum turgidum*, *Digitaria marginata*, *Cenchrus Prieurii*, *Aristida pallida*, *Latipes senegalensis*, *Sporobolus spicatus* and *Eragrostis pallescens*. Occasional valleys were marked with a carpet growth of herbs, *e.g.*, *Cyperus maculatus* and *Rhamphicarpa fistulosa*.

V. Agriculture.

1. Population.

The Colony of French Soudan in 1932 covered an area of 561,317 square miles with a mean population density, according to the census of July 1931, of 5·09 per square mile (5). This has risen from 4·66 in 1927. Native races constitute 99·19 per cent. of the population. From 1st January 1933, 19,952 square miles of the suppressed Upper Volta Colony have been added. The particulars given in Table XVIII refer to the administrative circles in the region of the middle Niger (19).

TABLE XVIII.

Population in 1926.

Circle	Area in square miles	Population	Density per sq. mile
Segou	1,544	193,173	125
Macina	1,158	84,891	73
San	579	149,131	258
Mopti	578	122,031	218
Niafunke	865	131,573	152
Goundam	2,158	93,391	43
Timbuctoo	19,300	60,874	3

A very high proportion of the total population is concentrated in a few large towns and villages along the main river-banks. The populations of some of the larger towns are as follows: Segou 8,229, Mopti 4,275, San 3,582, Goundam 4,251, Djenne 5,450 and Timbuctoo 6,118.

The great bend of the middle Niger is the meeting place of three of the six comprehensive African races—the Negroes to the south, the Semites to the north-west and the Hamites to the north-east. Races and tribes are very intermingled, and one tribe frequently inhabits one half of a village and another the other half. The following appear to be the more important races encountered in this region :—

Bozo.—Essentially a river race, semi-nomadic, with fishing almost their sole occupation. Scattered throughout the area.

Bambara.—A comprehensive race that seems to cover a number of related agricultural tribes in the south-western half of the area.

Hobo.—Agricultural tribes inhabiting the Bandiagara mountains.

Peuhls (*Fulani*).—Essentially a nomadic pastoral people though many of the more wealthy families have settled in the villages.

Touaregs and Tibu.—Nomadic, bellicose, desert people who are frequent visitors to the northern districts.

Moors (*Berbers*).—Similar to the Touareg but rarely met outside such towns as Timbuctoo.

Except for the northern limit of the area in the region of Lake Faguibine, where occasionally small bands of armed Touaregs carry out minor raids, the region is completely settled and is well covered by district administrative posts, while there are small schools in all the towns of any size. No part of the suspected outbreak area is more than 110 miles from an aerodrome.

2. Crops.

Only a minute percentage of the land is cultivated. The farmland is usually limited to within a mile or two of each village, though there is always a much larger area denuded of trees. Above and around the inundation zone a large variety of crops are grown, especially millet, guinea corn, maize, cassava, rice, groundnuts and cotton. Within the inundation zone itself rice is almost the sole crop, though small quantities of the other crops are grown on the islands and sandy ridges ; cotton on the heavy soils, and grains on the sandy soils. North of the inundation zone near Timbuctoo guinea corn and millet seem to be the only important crops.

At the present time an important irrigation scheme is being launched between Sansanding and Mopti. A barrage 1,200 metres long is to be built near Sansanding, and the flood water diverted through channels to irrigate a large area, north of the river, from Sansanding to Lake Debo now sparsely inhabited, with the intention of attracting the population from the more desert regions. The population of the 3,700 square miles to be irrigated is now 150,000, and it is hoped to increase it to 800,000 within a few years ([6, 5]).

3. Live Stock.

The middle Niger is an important stock-raising area. The Peuhls own numerous large herds of cattle, and some that were seen consisted of several thousand head. There is little doubt that their grazing has a considerable effect on the vegetation. Although the cattle were frequently seen in the *Vetiveria* belts, and although this grass is practically the only one that remains green throughout the year, it is not considered good grazing.

Sheep and goats are bred in quantity throughout, and in certain districts, particularly near Dire and Niafunke, considerable attention is given to wool production (there is a government sheep-breeding station at El Oualadji). The largest flocks of sheep are found on the Borghu plains at low water.

Donkeys are abundant and are bred principally in the Niafunke-Debo district. Horse-breeding is extensive, especially towards the north, and large numbers live on the Borghu plains, even after the commencement of the flood, living quite an amphibious existence. Camels are scarce and breeding is limited to the regions north of Faguibine and Timbuctoo.

4. Bush Fires.

It was thought at the commencement of these studies that bush fires might be one of many factors that determine the distribution of the *solitaria* and that might cause concentrations. Unfortunately the present survey was not long enough to carry out detailed observations. Though the fires probably commence very early in the dry season in non-flood areas, possibly as early as October, they continue very late. During May, near Macina, while large areas had been burnt to the ground, others were untouched and some had been burnt so early that the destruction had been incomplete. The fires were still continuing at this time.

In some localities the zonation caused by fires was very curious. For instance in a shallow valley at Benenigeni the lowest level, where the vegetation consisted of *Vetiveria* in open clumps mixed with other grasses, had been well burnt, the sides of the valley, covered with dense pure *Vetiveria*, were untouched, and the ridges on either side covered by *Andropogon* were burnt. It is apparent therefore that the *Vetiveria* will escape from the bush fires when it grows in pure stand, but when mixed with other less succulent grasses that dry off quickly it will be damaged. It is, however, only very occasional clumps of *Vetiveria* that are ever burnt down to the ground. The damage by fire to the larger species of *Cyperus* is similar to that done to *Vetiveria*, though as the *Cyperus* is always found at a lower level than the *Vetiveria* and nearly always grows in pure stand, it is still less likely to suffer complete destruction.

VI. Methods for Studying the Acridid Fauna.

The following was the normal procedure for examining the main centres for the study of the topography, vegetation, soils and the ecology of the Acrididae.

1. District Survey.

Several days were spent touring the district on foot in at least three different directions, visiting the various vegetation belts, collecting herbarium specimens and soil samples, photographing the vegetation and taking time observations to determine the population density of the *solitaria* by the methods described below.

It was soon decided that the best method for estimating the abundance of the *solitaria* was for one or more observers to walk at a standard pace (estimated at 2½ m.p.h.) through the habitat counting the locusts put up during a known period. The average number noted by one observer during one hour was termed the " time observation index " (T.O.I.), and very roughly this represents the number of *solitaria* per 20 acres. To facilitate counting when the locusts were abundant a small hand-counter was found invaluable. This method, however, has its limitations, since the activity of the locusts depends on the weather conditions especially temperature, and the number observed depends on the velocity of the wind and the relation between the directions of the line of march and the wind. When walking with a strong wind some of the locusts get up almost at the observer's feet and fly behind unobserved ; while walking with the wind many locusts fly ahead, settle, and are put up again, so that it is difficult to avoid counting the same individual a second time. Neither is it easy to standardise the walking speed through different types of vegetation, very tall or short grass, or over sand and mud or through swamps.

In order to test certain aspects of the T.O.I. method a detailed experiment was undertaken on 26th May in the extensive *Vetiveria* habitat behind Dar-es-Salaam near Diafarabe. Observations were taken at intervals throughout the morning simultaneously by three observers (myself and the two assistants) walking along parallel courses. Commencing at 6.0 a.m., 20 minutes after sunrise, we walked at a steady pace for half an hour due north-east, returning down the same course from 6.30 to 7.0. This procedure was repeated between 8.0–9.0, 10.0–11.0 and 12.0–1.0. The direction N.E. was chosen with the hope that it would be at right angles to the direction of the wind, but the wind blew unexpectedly from the S.W. after the early morning calm. The wind velocity gradually increased to a maximum of about 17 m.p.h. at about 9.0 a.m. and then slowly fell to about 2 m.p.h. at 1.0 p.m. Wet and dry bulb shade temperatures were taken at intervals throughout the morning, and the day was very typical with slight cloud up to 9.0 a.m. and brilliant sunshine afterwards. The temperature rose from 79° to 97°F., and the relative humidity fell from 81 to 48 per cent. during the experiment. The results of this experiment are shown in fig. 1 and the following are the main conclusions.

(*a*) The number of locusts observed rises fairly steadily and very considerably during the morning with the rise in temperature. The average between 6.0 and 6.30 was 17, and between 12.0 and 12.30, 63.

(*b*) The relative direction of the wind to the line of march is very important. When the wind was very slight, at both the beginning and the end of the experiment, there was little difference between the counts of the outward and inward journeys ; but when the wind was strong the numbers of locusts observed walking against the wind was about 30 per cent. less than when walking with it, in spite of taking every precaution not to count the same locusts twice.

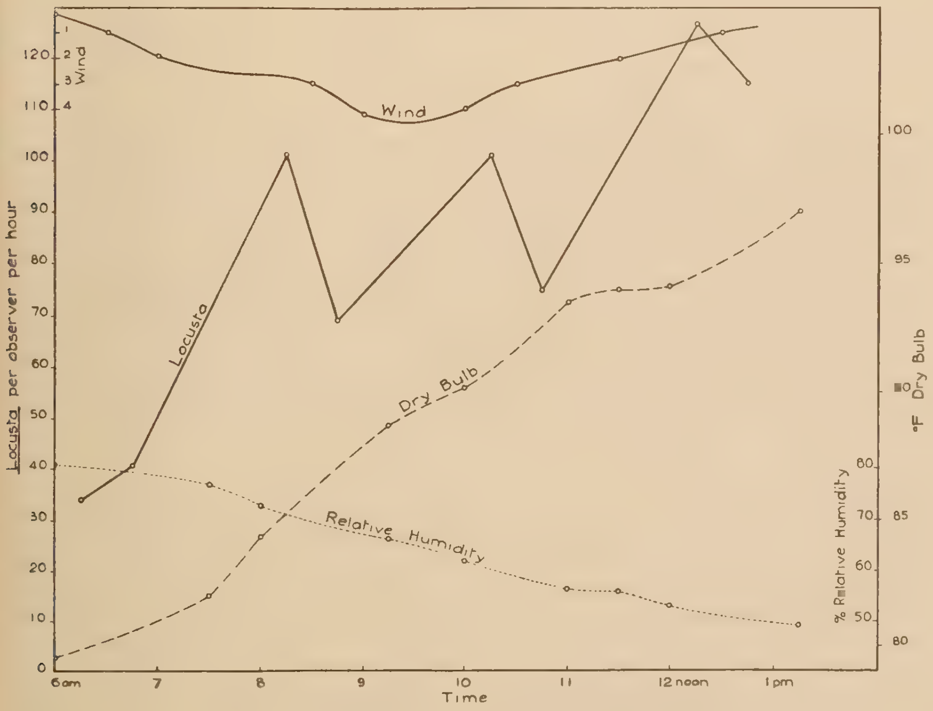

Fig 1. Diurnal activity; Diafarabe, 26th May, 1932.

(*c*) Between 9.0 and 10.0 a.m. appears to be the best time for such observations, but in order to make the T.O.I. at all accurate a series of similar experiments should be carried out so that rough corrections, according to temperature, can be made to all observations. Should T.O.I. observations be taken at only one temperature the number of determinations that could be made would be limited very seriously.

(*d*) When the wind is over 2 m.p.h. all observations should be taken walking at right angles to the wind.

TABLE XIX.

Time a.m.	Locust counts by different observers			
	Q.E.A.Y.	O.B.L.	J.K.A.	Average
6.0–6.30	12	11	28	17
6.30–7.0	18	20	23	20
8.0–8.30	37	50	65	51
8.30–9.0	33	38	33	35
10.0–10.30	44	67	40	50
10.30–11.0	29	37	47	38
12.0–12.30	58	75	57	63
12.30–1.0	45	72	56	58
Total	276	370	349	332

(*e*) Table XIX shows the differences between the counts of the individual observers, though it is not known whether the differences were mainly due to the disparity of our observational powers or to the uneven distribution of the *Locusta*.

The T.O.I. method worked fairly satisfactorily during the early part of the investigations, but after the arrival of migrating swarms of *gregaria* from the south it became rather impracticable, since it is impossible to distinguish the phases in flight. After the arrival of the swarms there were scattered *gregaria* individuals almost everywhere on the open plains, and under these conditions the only possible way to determine the *solitaria* populations was to follow T.O.I. observations by mass *Locusta* collecting, so that the percentage of *solitaria* amongst all the *Locusta* might be determined and the T.O.I. figures corrected accordingly. In the limited time available this was possible only in a few localities.

2. **Habitat Survey.**

After the district survey representative habitats of different types were selected for the analysis of the Acridid populations by means of mass collecting by a definite number of boys (usually about 10) over a definite period of time. The boys were instructed to collect all insects, and thus an indication of the relative abundance and the association of most species in the habitats was obtained. The calculated number of each species collected by 10 boys in one hour is termed the " time collection index " (T.C.I.).

It is extremely difficult, however, even in the early morning, to catch the larger and more active species such as *Ornithacris* and *Anacridium*, which are very timid and fly rapidly away with the usually strong wind. This method also fails when comparing tall, dense, almost impenetrable grassland with the lawn-like areas, and no method was devised for making such a comparison.

3. Analysis of Locusta Population.

Within those habitats where *Locusta* had been observed mass collections were made by as many natives as could be enrolled. To obtain a sufficient number of specimens for analysis it was found necessary to pay the natives by results, 50 c. being given for each locust taken. The difficulty of catching the *solitaria* is shown by the fact that the average cost for this work rarely exceeded 1 fr. per head for a morning's work. Boys worked very much better than men, and small leafy branches, especially of *Bauhinia reticulata*, were found to be suitable weapons for knocking down the flying locusts, as there was not a sufficient supply of nets.

Specimens were classified according to sex and colour (general body colour, colour of hind tibia and colour of fasciae on hind femur). The length of the elytron (E) and hind femur (F) was measured to determine the ratio of the femur to elytron (E/F) and sexual dimorphism, and a sample of the females was examined to determine the state of development of the ovaries.

During the early work at Diafarabe the mass collecting was frequently commenced very early in the morning, but it was found that the number of locusts collected before 8.30 was very small. It is probably a waste of time to collect before then or after 10.0 or 10.30 during normal hot weather, when the locusts are so active as to make collecting very difficult.

VII. *LOCUSTA*, PHASE *SOLITARIA*.

1. Distribution.

(1) *Seasonal.*

Adults.—Adult *solitaria* were found throughout the duration of the survey, the first specimens being taken at Funa, near Macina, on 5th May. During the period 9th–15th May adults became more and more numerous at Macina. The increased activity coincided with the gradual increase of the atmospheric humidity. As no hoppers were present at this time it appears probable that at least the latter part of the dry season is passed in the adult stage. This generation is termed the F_1 generation. Copulation was first seen on 23rd May at Diafarabe, but on the 21st the locusts had been seen to get up in pairs, indicating that breeding had begun.

Hoppers.—No hoppers were discovered until 20th June at Benenigeni, near San. A few days later freshly matured adults (F_2) were taken at San, suggesting that the first hoppers may have hatched about the end of May in this region.

Number and time of generations.—Attempts were made to elucidate the chronology of the breeding seasons and generations by examination of the ovaries of the females, and by classifying the instars of the hoppers. Except for the newly matured adults it is impossible to distinguish young *solitaria* from old, though this is a fairly simple matter when dealing with adults of phase *gregaria*. The analysis of the hopper and ovarian development data is shown in Tables XX and XXI and the following are the general conclusions.

Details of the life-history of *solitaria* seem to be little known and the durations of the different stages appear to vary greatly. Johnston and Maxwell-Darling (8) give the length of the incubation period during experiments in the Sudan in 1926 as 7–12 days with an average of 8·5 days, and in 1930 as 14–15 days with an average of 14·7 days, while Faure (7), working at Pretoria, found the egg stage to last 3–4 weeks in outdoor cages in warm weather. In Australia eggs laid in May took 14–18 days to hatch and those laid in July took 36 days (18). Johnston and Maxwell-Darling found the total duration of the larval stages to be 27–30 days, while Faure gives 8–10 weeks. Not knowing the average cycle under French Soudan conditions, it is not possible to work back from the date of any instar to the probable time of oviposition.

In the South-west area the ovaries apparently began to develop in the Macina-Diafarabe districts early in May, and copulation commenced at Diafarabe about 25th May, so that the first eggs were probably laid in the first week of June. Near San the development was probably more advanced, as the F_2 generation of adults began to appear towards the end of June. The rains at San were correspondingly earlier than at Macina, as shown in Table VI. This province was not visited again until the first week in September, when the analysis of both hoppers and ovaries indicated that a new generation of adults was just beginning to appear, giving an interval of roughly 13 weeks since the first eggs were laid by the F_1 generation. From Johnston and Maxwell-Darling's figures this would be the F_3 generation, and from Faure's figures the F_2 generation, and the former seems the most probable.

TABLE XX.

Incidence of Hopper Instars in solitary Locusta.

Locality	Date	Number of hoppers collected	Hopper instars % I	% II	% III	% IV	% V
Benenigeni	June 20	12			50	25	25
San	,, 21–23	18		11	33	28	28
Seyna	,, 29–30	6			50	33	17
Mopti	July 1–3	8			12	50	38
Korienze	,, 17	10		50	40	10	
Lake Korienze	,, 20	137*	1	9	39	44	7
Sarafere	,, 25–29	13		15	31	31	23
Kabara	Aug. 14	4		25	50	25	
Dire	,, 17–18	7		57	29		14
Diafarabe	Sept. 7 & 8	9				33	67

* Hoppers, mainly *transiens*, of uncertain origin.

In the Central area, from the ovarian examinations at Korienze and Sarafere it would appear that in the middle of July there were a few of the F_1 generation sexually mature and many F_2 with undeveloped ovaries, and at the end of the month the F_1 had died off and the ovaries of the F_2 adults were developing. From the hopper examination it would seem that at Mopti the F_2 adults would begin to appear early in July, at Korienze at the end of July and at Sarafere early in August. There are no indications of when the F_2 oviposited.

In the North-east area, from the ovarian examination it would appear that some of the F_1 were still sexually mature about the middle of August, though at Dire on 17th and 18th August the ovarian development of the few specimens taken was only just commencing, being behind that of specimens taken on 3rd August. The hoppers, on the other hand, indicate that the first eggs were laid at the end of July and that the F_2 adults would appear in September.

TABLE XXI.

State of Development of Ovaries in solitary Locusta.

Locality	Date	Number of females examined	State of development of ovaries			
			% Nil	% Slight	% Medium	% Full
Funa	May 6	5	100			
Macina	,, 14	6	50		33	17
Diafarabe	,, 22–27	28		39	18	43
Benenigeni	June 20	1				(100)
San	,, 23	5	60		20	20
Korienze	July 16 & 17	8	75			25
Sarafere	,, 25–29	27	85	11	4	
El Oualadji	Aug. 1	1		(100)		
Dire	,, 3	18		55	17	3
Nr. Korioume	,, 7	2				100
Kabara	,, 13 & 14	17		12	29	59
Dire	,, 17 & 18	5	60	20	20	
Diafarabe	Sept. 7 & 8	1	(100)			

It appears, therefore, that in 1932 the generations were rather indefinite and overlapped considerably, owing perhaps to spasmodic early rainfall, variation in the developmental period (eggs and hoppers) and different parental origins (indigenous *solitaria* and swarm stragglers). The probable chronology is given in Table XXII. It should be noted that this does not agree with the views of Zolotarevsky (^{17}), who considers that there are only two reproductive periods per annum, the first in May or June and the second in November or December.

(2) *Geographical Distribution.*

Solitaria were found throughout the Niger valley from Macina to Kabara, and up the Bani to Benenigeni. They were not found away from the river valley towards Bandiagara or Timbuctoo.

(3) *Ecological Distribution.*

The *solitaria* were confined to the inundation zone, and within this limit were never found in any type of orchard or park country, or in the strand vegetation. They were taken only in open grassland, and even within this belt showed marked preference for certain types of dense vegetation.

The following are descriptions of all the habitats where the *solitaria* were found with indications of their abundance.

(i) *Funa.*

6th May. Open grassland consisting of high (5–10 ft.) *Andropogon giganteum*, very dense and dry, with dense, dry undergrowth of other shorter undetermined grasses and very occasional bushes of *Bauhinia reticulata* (about 2 to 10 acres) dwarfed by fire. Parts of this area were being cultivated for rice.

6.10–6.40 and 6.50–7.20 a.m. Bright sun to slight haze; wind, S.E., 5 m.p.h. T.C.I. = 7.

(ii) *Macina.*

(*a*) North bank. 10th May. Open mixed grassland mainly in tufts, *Vetiveria nigritana*, *Andropogon giganteum* and *A. gayanus* dominant, mostly low growth after fire, but some dense patches about 4 ft. high. Very occasional *Bauhinia* and *Mitragyne africana* trees; soil dry, fissured clay.

6.40–7.0 a.m. Bright sun; wind S.W., 2 m.p.h. T.O.I. = 1·5; T.C.I. = 0·0.

(*b*) North bank. 10th May. Similar to (*a*) but some of the closed growth up to 8 ft. high. *Vetiveria* and *A. gayanus* dominant. No trees.

7.40–8.10 and 8.15–8.45 a.m. Bright sun; wind S.W., 15 m.p.h. T.O.I. = 21·5; T.C.I. = 0·0.

(*c*) South bank. 11th May. Narrow belt of pure dense *Vetiveria*, average height 3 ft. Half the grass dead, half green. Very little open soil. Heavy sand.

6.40–7.10 a.m. Bright sun. T.O.I. = 7·0; T.C.I. = 12·0.

(*d*) South bank. 11th May. Patch of pure *Cyperus auricomus* (150 × 150 yds.) round a dried up pool, in tufts covering about 50 per cent. of the soil, about 2 ft. high. Soil very heavy and dry.

8.10–8.25 a.m. Bright sun. T.O.I. = 8·0; T.C.I. = 4·0.

TABLE XXII.

Solitaria Generations.

Generation	Stage	S.W. Area	Central Area			N.E. Area
			Mopti	Korienze	Sarafere	
F_1	Adult	– June	– June	– July	– July	– Aug.
F_2	Egg Hopper Adult	June June–July July–Aug.	June June–July July–Aug.	July July–Aug. July–Sept.	July–Aug. Aug. Aug.–Sept.	July–Aug. Aug.–Sept. Sept.
F_3	Egg Hopper Adult	Aug. Aug.–Sept. Sept.	?	?	?	?

(*e*) North bank. 12th May. As (*b*). Impossible to count the *Locusta* owing to high wind, but they appeared to be more numerous than on 10th May.

6.55–7.25 a.m. Bright sun; wind, W.S.W., 21 m.p.h. T.O.I. probably about 50·0; T.C.I. = 8·0.

(*f*) North bank. 12th May. *Cyperus auricomus* as (*d*) but much denser.

8.30–9.0 a.m. Bright sun; wind, W.S.W., 27 m.p.h. T.O.I. = 1·0; T.C.I. = 0·0 (probably due to wind).

(*g*) North bank. 14th May. As (*b*) and (*c*).

6.40–7.40 a.m. Bright sun; wind, S., 21 m.p.h. T.O.I. = 12·0; T.C.I. = 12·0.

(iii) *About 8 miles West of Diafarabe, N. Bank.*

(*a*) 16th May. Open level grassland plain. *Vetiveria* dominant in rather widely separated tufts, burnt to within a few inches of the ground, with very few fresh small leaves, some *A. giganteum.* Soil heavy, dry clay.

7.30–8.0 a.m. Bright sun. T.O.I. = 138.

(*b*) 16th May. As (*a*), but *Vetiveria* about 6 ft. high in widely separated tufts, quite dry. Some small patches with *A. giganteum* dominant and indications that *A. gayanus* had been diffused through the *Vetiveria,* but had been burnt to the ground.

8.0–8.30 a.m. Bright sun. T.O.I. = 378.

(iv) *Diafarabe, N.E., Dar-es-Salaam plain.*

(*a*) 18th May. Extensive plain of 30–40 square miles, without trees, covered with almost pure *Vetiveria* in very large, well-separated tufts, occasional small patches of dead *Cyperus.* Soil, heavy clay.

7.0–7.15 a.m. Bright sun. T.O.I. = 44.

(*b*) 18th May. As (*a*), but *Vetiveria* not so high and clumps not so widely separated, with young grass (undetermined) just coming up between tufts. Frequent small depressions with tall *Vetiveria* mixed with some *C. auricomus.* Soil lighter, with crumbling surface.

7.30–7.40 a.m. Bright sun. T.O.I. = 126.

(*c*) 18th May. As (*a*) but *Vetiveria* very dense with practically no open soil.

8.0–8.15 a.m. Bright sun. T.O.I. = 69.

(*Note*: Taking (*a*), (*b*) and (*c*) as one habitat (18th May), the average T.O.I. for the plain is 73·5 (7.0–8.15 a.m.).

(*d*) 18th May. As (*a*) but towards the edge of the open plain with occasional trees (including *Mitragyne* and *Bauhinia*) in groups. *Vetiveria* short.

9.30–9.45 a.m. Bright sun. T.O.I. = 60.

(*e*) 22nd May. As (*a*).

7.0–10.0 a.m. Sun through light clouds. T.C.I. = 3·8 (labour paid per hour).

(*f*) 23rd May. As (*a*).

7.0–10.0 a.m. Cloudy at first, then hot sun. T.C.I. = 7·6 (labour paid per locust).

(*g*) 27th May. As (*a*).

7.0–10.0 a.m. T.C.I. = 7·6 (labour paid per locust).

(*h*) 29th May. As (*a*).

10.0–10.30 a.m. Bright sun; wind, N.E., 27 m.p.h. General conditions exceptional with return of harmattan. Temperature at 10.30 a.m. 99·6°F. (shade), relative humidity 38 per cent. T.O.I. = 39 (walking down wind).

(*i*) 2nd June, as above.

6.45–10.15 a.m. Bright sun, but cooler than usual. T.C.I. = 9·5 (corrected by mass collection = 8·3).

(v) *Diafarabe; N.W. plain, beyond River Diaka.*

(*a*) 19th May. Open *Vetiveria* of medium height and spacing with occasional *C. auricomus* and patches of *A. giganteum.* No trees; very similar to iv (*b*).

7.15–7.40 a.m. Bright sun. T.O.I. = 94.

(*b*) 19th May. The intermediate zone between the grassy plain and parkland with *Vetiveria* and *A. gayanus* equally dominant.

8.0–8.16 a.m. Bright sun. T.O.I. = 75.

(*c*) 19th May. Small belt of *A. gayanus* of medium height and spacing at edge of parkland.

8.25–8.33. Bright sun. T.O.I. = 37.

(*d*) 19th May. In the parkland (*Bauhinia, Mitragyne,* etc.) with many grasses about 3 ft. high. Termitaria frequent.

9.0–9.10 a.m. Bright sun. T.O.I. = 54.

(vi) *Diafarabe; Rounde Island, 20th May.*

Locusta were found only amongst the *Vetiveria,* where the T.O.I. was less than 1·0.

(vii) *Diafarabe; South bank.*

(*a*) 21st May. Open grassland, mainly *Vetiveria,* short and open.

7.10–7.22. Sun breaking through morning cloud. T.O.I. = 62.

(*b*) 21st May, as above but *Vetiveria* more open.

9.0–9.15 a.m. Bright sun. T.O.I. = 12.

(viii) *Miyatiki.*

(*a*) South-east bank. 30th May. Open level plain with no fresh growth of grass except in swampy depressions or on occasional slight ridges with open *Vetiveria.* Ground covered with straw of various grasses, probably mainly *Echinochloa pyramidalis* and *E. stagnina.*

5.30–6.30 p.m. Bright sun. T.O.I. = 1·0.

(*b*) 31st May. As above.

9.30–10.45 a.m. Bright sun. T.O.I. = 0·8.

(*c*) North-west bank. 31st May. Level plain as above.

6.30–9.25 a.m. Bright sun. T.O.I. = 1·0.

(ix) *Mopti.*

(*a*) North bank. 11th June. Narrow valley with dense, pure *Cyperus maculatus.*

8.0–8.15 a.m. Bright sun; wind, W., 10 m.p.h. Shade temperature near ground amongst vegetation 87°F., relative humidity 51 per cent. T.O.I. = 432 (walking with wind), corrected by mass collection = 52.

(*b*) North bank, 11th June. Open level plain above the valley (*a*) with vegetation as at Miyatiki (viii (*a*)–(*c*)).

8.0–8.15 a.m. Bright sun; wind, W. 10 m.p.h. Shade temperature near ground 88°F., relative humidity 48 per cent. T.O.I. = 48 (walking with wind), corrected by mass collection = 6.

(*c*) As (*a*), 3rd July.

8.0–8.15 a.m. Bright sun; shade temperature near ground 87°F., relative humidity = 46·5 per cent. T.O.I. = 212 (uncorrected).

(*d*) As (*b*), 3rd July.

8.0–8.15 a.m. T.O.I. = 41 (uncorrected).

(x) *Benenigeni.*

20th June. Undulating grassland beside the Bani, with *Vetiveria* in the valleys and *Andropogon* on the ridges. A few *solitaria* seen amongst the *Vetiveria.*

(xi) *San.*

(*a*) 22nd June. Grassland plain east of San covered with a mixed growth of grasses with *Vetiveria* dominant though widely spaced. Fresh growth, after fires, about 1½ ft. high. The only *solitaria* taken were in a dried up watercourse where the vegetation was mainly *Cyperus auricomus* with some bushes of *Mimosa asperata* where the relative humidity was 65·5 per cent. as compared with 61 per cent. on the plain.

7.45–8.15 a.m. Bright sun; shade temperature 87°F. T.C.I. = 6·7.

(*b*) 23rd June. Same plain as above but more to the north.

7.55–8.12 a.m. Rather cloudy, temperature 86°F., relative humidity 62 per cent. T.O.I. = 6·7.

(xii) *Seyna.*

29th June. Typical open *Vetiveria* plain. *Locusta* common.

(xiii) *Fotoma* (*near Mopti*).

7th July. Narrow dry valley, pure dense *Vetiveria* with occasional *Mitragyne* trees. Orthoptera very abundant with many *Locusta*, but though a number of the females had pink tibiae the femoral proportion of only one (2·05) was under 2·10.

(xiv) *Konna.*

12th July. Small depression of about 3 acres covered with dense *Vetiveria.*

7.0–9.30 a.m. Bright sun. T.C.I. = 0·4 (corrected).

(xv) *Korienze.*

(*a*) 16th–17th July. Fairly dense and tall pure *Vetiveria* round the shore of Lake Kogi. *Solitaria* common amongst many swarm stragglers.

(*b*) 18th July. Western fore-shore of Lake Korienze. Wide level Borghu plain. Only one *solitaria* seen.

(*c*) 18th July. Eastern fore-shore of Lake Korienze. Wide plain covered with a carpet of prostrate herbs. Only one *solitaria* seen.

(xvi) *Near Rocher Marie Therese.*

21st July. Typical *Vetiveria* plain to the north-east of the outcrop. Only two *solitaria* seen.

(xvii) *Sarafere.*

(*a*) 25th July. Plain to the west. Extensive belt of *Vetiveria*, very dense and of medium height with most of the ground covered with straw and with *Cynodon dactylon* in places.

9.10–9.30 a.m. Overcast and some drizzle. T.O.I. 397 (corrected = 188).

(*b*) 25th July. Open plain below *Vetiveria* level (*a*) towards a stream. Ground covered with loose straw as at Miyatiki.

8.30–9.0 a.m. Overcast and drizzle. T.O.I. = 79 (corrected = 38).

(*c*) 26th July. North-west plain. Typical open *Vetiveria*. A few *solitaria* seen but no counts possible owing to many swarm stragglers.

(*d*) 29th July. As (*a*).

7.30–8.30 a.m. Cold with slight rain ; temperature at 9 a.m. 74°F. T.C.I. = 11 (corrected).

(*e*) 29th July. Small swamp on north-east plain. Tangled mass of short vegetation growing in wet mud.

5.0–5.30 p.m. Bright sun. T.C.I. = 5.

(xviii) *El Oualadji.*

1st August. North bank, amongst the orchard thorn bush on the undulating sandhills there are occasional small areas of *Vetiveria* ; in the depressions in one of these a few *solitaria* were observed.

(xix) *Dire.*

(*a*) 3rd August. In grassland round the Hemgu swamp ; nearly pure *Scirpus maritimus*, completely dried up, in tangled masses about 3 ft. high.

6.0–8.0 a.m. Hazy and hot ; shade temperature 5.30 a.m. 84°F. and 9.0 a.m. 90°F. T.C.I. = 9.

(xx) *Bouramodire.*

5th August. Fairly large areas of open grassland covered with straw but with occasional zones of dense *Vetiveria* and *Scirpus maritimus*. *Solitaria* common in the tall vegetation.

(xxi) *Between Koiretago and Korioume* (*North bank*).

7th August. Open level plain covered with straw ; occasional *solitaria.*

(xxii) *Kabara.*

13th and 14th August. Open plain between village and river. Mostly covered with old straw, but extensive areas of *Vetiveria*, usually rather open but occasionally very dense. *Cynodon dactylon* on the sandy ridges. *Solitaria* common.

(xxiii) *Lake Horo.*

21st August. Extensive area of *Vetiveria* just being submerged by the rising lake. No *Locusta* where the ground was under water, but *solitaria* common further back.

(xxiv) *Diafarabe, north-east, Dar-es-Salaam Plain.*

5th–7th September. *Vetiveria* now standing in 1–2 ft. of water. Very few *solitaria* seen, but observation difficult.

(xxv) *Diafarabe, north-west plain, beyond River Diaka.*

8th, 13th and 15th September. The whole plain now under 1–3 ft. of water with the vegetation up to 9 ft. high, very dense and mixed. Only a few *solitaria* seen.

It will be seen that the preferred habitat of the *solitaria* appears to be the *Vetiveria* zone (2 (*b*) (iv)), though they are also found fairly abundantly in the dense *Cyperus* 2 (*b*) (i) associations. Both these plants offer green food through the year and the dense tufts form excellent retreats from which the locusts cannot be taken by insectivorous birds, of which *Merops nubicus nubicus* is probably quite important in reducing the number of *solitaria*. Both plants normally escape destruction by bush fires. The *solitaria* probably tend to become concentrated in these associations towards the end of the dry season, but their ecological range probably increases during the rains with the end of the fires and the extension of fresh vegetation. The *Cyperus* is always found on low-lying heavy clays that are unsuitable for oviposition and which are flooded early during inundation. It appears that the *solitaria* tend to migrate away from the rising river.

The open Borghu plain offers no shelter during the xerophytic phase and it is hardly surprising that the *solitaria* are very scarce there. It has also been shown in Section III, **4,** that the ecoclimates of the *Vetiveria* and tall *Cyperus* associations are more humid than that of the open plain and therefore probably better suited to the locusts. The ecoclimatic observations also indicate that the tall, dry grass association is very dry and hot, and this probably explains the scarcity of the *solitaria* in such habitats in spite of the protection offered by the vegetation.

2. Behaviour.

The nature of the diurnal activity cycle is indicated in Section VI, **1.** In addition, at Sarafere, it was observed that on a cold wet morning the *solitaria* became active earlier than the *gregaria*.

From general observations it is thought that the *solitaria* rarely fly unless disturbed by a passing man or beast. After flight they usually dive into a tuft of *Vetiveria* grass and work their way down to the base, where they will lie as dead even when the tuft is pulled to pieces. *Solitaria* have also been seen to emerge from the deep crevices in the clay soils. They very rarely settle on the grass and when they rest on the bare soil they always face the wind and when disturbed rise into the wind, then turn and drift some 30 or 40 yards down wind. If, therefore, a *solitaria* habitat is frequently disturbed by man or game, there will be a tendency for the locust population to migrate gradually across the habitat in the direction of the prevailing wind.

The possibility of a migration of the *solitaria* population should not be ignored in studying its distribution. The migratory habit is so well developed in phase *gregaria* that it would not be altogether surprising to find the same instinct active, though much less pronounced, in phase *solitaria*. The writer (10) considers that the seasonal movements of the atmospheric humidity belts is largely responsible for the mass migration of locust swarms. It is thought that normally the swarms eventually arrive at the humidity preferendum by the method of trial and error, but since this can only be achieved by continuously active insects it is unlikely to hold true for the *solitaria*, which rarely fly if undisturbed. Perhaps this instinct only serves to lead them to the habitats with suitable ecoclimates. The *solitaria* were never observed to fly at any height above the grassland or across any wide waterways and were never found in parkland. Any migration that occurs is therefore likely to be limited to each individual habitat and does not spread across the intervening parkland or water from one grass habitat to the next, but if a wind blows regularly in the same direction it is not inconceivable that the *solitaria* population would be concentrated along the leeward edge of a habitat.

One male *solitaria* was taken pairing with a female *gregaria*.

The effect of a swarm passing over an area inhabited by many *solitaria* was observed at Diafarabe in May. It is almost certain that no flying swarms had visited the district between about October and 28th May, when a rather scattered swarm about two miles in length drifted over the Dar-es-Salaam *Vetiveria* habitat in the afternoon, passing from east to west. The *solitaria* population was studied in considerable detail before and after the passing of this swarm. From the details given in Section VII, **1** (3) it will be seen that there was no apparent increase or decrease in the population as determined by T.C.I. counts taken on 27th and 29th May.

As detailed in Section IX the *solitaria* are separated into four classes according to their general body colour, and Table XXIII shows the incidence of these colour groups before and after the passing of the swarm. The main differences are the decrease in the numbers of greens and nearly blacks, which are shown later to be the most extreme *solitaria*, and the corresponding increase of the browns. This could be due to (i) some of the greens and nearly blacks joining the swarm, or (ii) the earlier maturation and death of these extreme *solitaria*. The latter possibility is the more probable, since if any *solitaria* were to join the swarm the brown, or less extreme *solitaria*, would be most likely to do so. The determinations of the elytron/femur ratio confirm the decrease in the extreme *solitaria*.

TABLE XXIII.

Solitaria Population, Diafarabe, before and after passing of flying Swarm.

Colour	Before swarm (22nd–28th May)			After swarm (28th May–2nd June)		
	Male %	Female %	Total %	Male %	Female %	Total %
Green	13	15	14	7	6	7
Brown	71	44	59	84	59	73
Nearly black	11	8	10	4·5	3	4
Typical *gregaria* ...	5	33	17	4·5	32	16
Number examined ...	106	86	192	88	63	151

The sex ratio changed from 84 females per 100 males before the arrival of the swarm to 72 after, indicating that the females were dying off earlier than the males. One other point arises from Table XXIII : both before and after the passing of the swarm a high percentage of the brown *solitaria* (66 and 67 per cent.) were males, while a high percentage of the typical *gregaria* (88 and 83 per cent.) were females.

On 20th July observations were taken on the south-western fore-shore of Lake Korienze on the driving effect of the rising lake. At this time the water had risen above the *Cyperus* belt that fringes the lake at low water and was spreading at the rate of some ten yards a day over the Borghu plain. In front of the advancing tide the Borghu was still in its xerophytic phase—the ground covered with dead straw—but as the ground became submerged the grass was sprouting vigorously. *Locusta* hoppers were very numerous throughout the unflooded area. They seemed to belong mainly to phases *solitaria* and *transiens*, and it is likely that they were the progeny of some very scattered swarm. Of the 137 hoppers collected 14 per cent. were coloured green, 85 per cent. were brown and there was one black hopper. Five time-collections were made down separate strips parallel to the shore ; the first in the very damp ground immediately beside the rising water ; the second and third some 30 and 60 yards back on dry Borghu ; the fourth in a strip of open *Vetiveria* a further 30 yards inshore ; the fifth on the fringing sandbank another 30 yards inshore. In each level hoppers were collected by 10 men for 15 minutes with the following results : 1st level 10 hoppers, 2nd 91, 3rd 30, 4th 6, 5th 0.

From these figures it is concluded that the hopper population of the Borghu plain was being gradually swept inshore by the rising lake, and this confirms our previous contention that the flood may assist the development of phase *gregaria* not only by reduction of size of habitat but by inducing forced activity. Lack of provisions prevented the continued observations in this locality that might well have yielded most interesting results.

3. Natural Enemies.

The most important avian predator is the bee-eater, *Merops nubicus nubicus*. This handsome bird which builds its nest in a hole in the ground in great colonies, usually in the river-bank, was very abundant along the river from San to Sarafere and was present throughout the rest of the riverain area. Nearly always when one walked across a grassland habitat populated with *solitaria* two or more of these birds would follow at a discreet distance ready to swoop and take in the air any locust that was put up. The bee-eaters were sometimes so numerous that the collecting of *solitaria* specimens was seriously handicapped. Though the birds appeared to find it difficult to distinguish *solitaria* on the wing from other large Orthoptera, especially *Ornithacris cyanea tereticollis*, they never seemed to eat these others but dropped them as rapidly as they discovered their mistake. It is thought that the spiny tibiae of the other Orthoptera protected them.

One species of bustard was frequently seen following swarms, though it was never actually observed to feed on *solitaria*.

VIII. *LOCUSTA MIGRATORIA MIGRATORIOIDES*, PHASE *GREGARIA*.

1. Adults.

The history of the swarms of *L. m. migratorioides* in the French Soudan from 1928 to 1931 has been given by Coleno. From his descriptions and maps it is apparent that the seasonal mass movements of the swarms are of the same type as those of the swarms in Nigeria. The swarms enter the colony, mainly from French Guinea, in May or June and until August they are passing in a general north-easterly direction through the region of the middle Niger. The first hoppers are found in the south-west of the colony in June and they hatch in the middle Niger in July. The return migration to the south-west begins near Timbuctoo about the beginning of September ; the middle Niger districts are free about the end of October, and the colony is nearly clear by the middle of November. Although no details of the late 1931 swarms have yet been published, the migrations were similar to those of the previous years, and no swarms were reported from the middle Niger from the end of October until May 1932.

Details of swarms observed or reported to me during the course of the present investigation are given in Appendix I. The sex ratios (S.R.) are given as the number of females per 100 males. The velocity of the wind is given in terms of the Beaufort scale. S.D.=sexual dimorphism, expressed as average length of female elytron as percentage of average length of male elytron. E/F=elytron/femur ratio. Type of swarm : L=large ; M=medium ; S=small ; D=diffuse ; C=compact.

On a few occasions, notably at Sarafere on 24th July, adults were attracted to light in the evening.

Observations on the relative directions of the flight of the swarm and of the wind were taken on 14 occasions. These may be summarised as follows :—

Angle of Flight to wind	Swarm No.	Wind Force (Beaufort scale)	Direction of Flight
0°	2	4	W
	10	2	WNW
	11	3	SW
	12	4	SW
	15	0·5	SE
	21	1	N
	35	4	NE
	37	4	E
22·5°	9	0–3	NE
	19	1	ENE
45°	18	1	ENE
67·5°	17	3	NNW
90°	7	3·5	NW
135°	8	0–3	NW

Although most swarms flew with the wind the direction of some was at quite a considerable angle and there seemed to be a tendency for swarms to move in a general north-easterly direction irrespective of the direction of the wind, so long as it was not above force 3, from the middle of July onwards.

The swarms began to get sexually mature about the middle of June, when the degree of wetness rose to 2° (Table X). The *gregaria*, therefore, seem to mature rather later than the *solitaria* under the same climatic conditions.

It is seen that in the samples examined females were almost invariably more numerous than males.

2. Hoppers.

Hopper bands were scarce since they were observed in only four localities during the survey.

1. *Sarafere.* 24th–29th July. Small primary bands of first instar hoppers were found on the 24th on a ridge of sandhills, amongst the *Hyphaene* palms and *Cynodon dactylon*. On the 28th several larger bands of 2nd instar hoppers were found in the same area, and on the 29th about one acre of 3rd instar hoppers were found in the farmland above the *Vetiveria* plain.

2. *Kabara.* 13th–14th August. On the 13th numbers of first instar hoppers were scattered over the dunes above the fore-shore and at 6 a.m. on the 14th many hoppers were observed hatching in the sandy soil near the edge of the plain amongst the *Cynodon dactylon.*

3. *River Niger, between Kabara and Dire.* 16th August. A large dense band of first instar hoppers was found above the bank of the river moving south across a strong east wind.

4. *Road from Segou to Bamako.* 5th October. For many miles second and third instar hoppers were found scattered over the road and the adjacent vegetation. Hopper bands had been reported and an anti-hopper campaign had started in the south-east of the circle of San by 21st June.

IX. COLOUR AND BIOMETRICAL ANALYSIS OF THE *LOCUSTA* POPULATIONS.

1. Characters of the Phases.

The following are the recognised principal morphological characteristics of the adults of the phases of *Locusta* :—

Phase solitaria :

(i) Colour variable but frequently green.
(ii) Black streaks on upper surface of pronotum normally absent.
(iii) Head relatively narrow.
(iv) Pronotum with high convex median keel, fore margin angular and hind angle acute.
(v) Low E/F ratio, usually 1·80 to 1·90.
(vi) Strong sexual dimorphism ; females much larger than males.
(vii) Hind tibiae pink or red.
(viii) Two black marks on inside of hind femur.

Phase gregaria :

(i) Colour brown, males yellow when sexually mature.
(ii) Two black streaks on upper surface of pronotum.
(iii) Head relatively broad.
(iv) Pronotum with low keel ; fore margin sub-acute and hind angle sub-acute, rounded.
(v) High E/F ratio, usually 2·10 to 2·20.
(vi) Slight sexual dimorphism.
(vii) Hind tibiae brown, yellow or grey.
(viii) One large black mark on inside of hind femur.

Phase congregans :

(i) Colour variable, mainly brown with green forms in minority.*
(ii) Pronotal streaks absent.*
(iii) —
(iv) Pronotum with high convex keel with hind angle as in phase *gregaria*.*
(v) E/F ratio low, but higher than in phase *solitaria*.*
(vi) Sexual dimorphism marked but less than in phase *solitaria*.*
(vii) Hind tibiae as in phase *gregaria*.*.
(viii) Two black marks on inside of hind femur.†

Phase dissocians :

(i) Colour variable with green forms dominant.*

There is no difficulty in distinguishing the average *solitaria* specimen from the average *gregaria* and intermediate forms are loosely classified as *transiens*, but there is as yet much uncertainty concerning the differences between the phases *congregans* and *dissocians*, and from the practical point of view this is a most urgent problem. It is foreseen that in the future locust control measures will be largely preventive and will depend on keeping a close watch on outbreak areas and on the suppression of any incipient swarms. For this purpose and for the study of causes of association and dissociation it is of importance to be able to distinguish *congregans* from *dissocians*. Zolotarevsky (^{15}) attempts to do so by the relative rates at which the phase characteristics change. Thus in phase *dissocians* the green coloration and in phase *congregans* the brown coloration appear very quickly and before the body proportions alter.

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* Johnston & Maxwell-Darling.[8]

† Zolotarevsky.[15]

In the present investigations the following characteristics are considered with two objects, (*a*) to determine the status of the solitary populations in the different localities and (*b*) to examine methods for separating the phases :—General body colour (and pronotal streaks), relative lengths of elytron and hind femur, sexual dimorphism, colour of hind tibiae, and marks on inside of hind femur.

Individuals of the *solitaria* phase were found of almost all shades from bright green and light straw to nearly black. For convenience all *Locusta* were classified into the following four main colour groups, and although this classification is quite arbitrary, it serves to indicate whether any one colour was dominant in any habitat or at any season or whether colour is correlated with the different phases as determined by body measurements.

(*a*) *Green.* Mainly dark apple-green, but including some very pale green.

(*b*) *Brown.* All shades of brown from light straw-colour to dark chestnut-brown. It was found impossible to divide this group.

(*c*) *Nearly black.* A distinctive group containing those with much black pigmentation.

(*d*) *Typical gregaria.* Those with all the various shades of colour typical of the gregarious phase—light brown, reddish brown and yellow—but all distinguished by the two dark streaks along the dorsal surface of the pronotum.

Whereas colour differences may be useful for separating the phases, biometric data are of much greater value for analytical purposes. The relative lengths of femur (F) and elytron (E) of locusts are expressed in the literature in two ways, either E/F or its reciprocal F/E. The former is preferred by the writer, as the ratio 2·00 is a conveniently evident rough limit for distinguishing the solitary and gregarious phases. Average E/F ratios have been calculated from the sum of the lengths of elytra or femora, and not by averaging the individual ratios. This latter method does not give the true average, although it has been adopted by some recent workers. Average ratios are, however, avoided as much as possible and variations are shown by frequency distribution tables and graphs. The E/F ratio can of course be obtained for individual specimens, while the degree of sexual dimorphism, expressed as the average length of the female elytron to that of the male, can only be obtained from fair-sized collections.

Uvarov (12) and Zolotarevsky (15) have pointed out that the hind tibiae of the *solitaria* are usually pink or red. During the present investigations it was found that it was only practicable to classify the colours of the hind tibiae of the males, as those of the females were of many indefinable tints. The male tibiae were divided into three groups, pink, yellow and intermediate. Zolotarevsky (15) has described and figured the hind femora of the phases *solitaria* and *gregaria* of *Locusta migratoria capito*, Sauss., showing that on the inside of the *solitaria* femora there are two dark fasciae, while in *gregaria* these two marks are merged together. It was possible to make a similar distinction with the *L. m. migratorioides* taken in the middle Niger, although there were a few intermediate forms and the specimens are therefore divided into the following additional three groups—double mark, single mark and intermediate.

As the only large catches were made at Diafarabe, these populations are examined in detail and the results are then applied to the other collections.

2. Diafarabe Collections.

1. *General Body Colour.*

The number of each colour group taken in the various localities is shown in Table XXIV and the same figures, expressed as percentages, for the few localities

TABLE XXIV.

Colour Analysis of Solitary Locust Population.
(Actual numbers.)

	Green			Nearly Black			Brown			Typical *gregaria*			Total		
	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total
Funa	2	1	3		1	1	3	7	10				5	9	14
Macina	4	2	6	1	1	2	5	2	7	7	3	10	17	8	25
Diafarabe (May) ...	20	18	38	17	9	26	149	74	223	9	50	59	195	151	346
Miyatiki		1	1				1		1				1	1	2
Mopti		1	1							6	12	18	6	13	19
Benenigeni							2	1	3	6	3	9	8	4	12
San	5	2	7	1	1	2	3	2	5	6	2	8	15	7	22
Seyna	1		1				2	3	5	1	1	2	4	4	8
Fotoma										13	13	26	13	13	26
Konna		1	1				8	3	11	41	43	84	49	47	96
Korienze	1	4	5				13	6	19	79	34	113	93	44	137
Sarafere	11	13	24				8	7	15	20	18	38	39	38	77
Dire	6	9	15				20	11	31	18	13	31	44	33	77
Horo	1	1	2		1	1	2	2	4	4	12	16	7	16	23
Koiretago		2	2				1		1				1	2	3
Kabara	2	11	13		1	1	4	4	8	11	10	21	17	26	43
Diafarabe (Sept.) ...	31	33	64				40	41	81	65	73	138	136	147	283
Total ...	84	99	183	19	13	32	261	163	424	286	287	573	650	562	1,212

where an appreciable number were collected, are given in Table XXV. Both these tables refer only to solitary locusts and not to samples of swarms, although many swarm stragglers are necessarily included.

(*a*) *Green.* These were only numerous in five localities—Funa/Macina, Diafarabe (especially in September), Sarafere, Dire and Kabara—though the percentage in the total catch at San was high (32 per cent.). It is noteworthy that the percentage taken at Diafarabe in May (11 per cent.) before the arrival of many swarms was lower than in September (22·5 per cent.) after this district had been invaded. The percentage at Sarafere was particularly high considering the number of swarm stragglers present there.

(*b*) *Brown.* These represented a fairly large percentage of the *solitaria* population in most localities. At Diafarabe the percentage dropped markedly from May to September. Faure (⁷) has shown how the colour of the *solitaria* varies with that of the environment, so that it was to be expected that at Diafarabe those that were bred during the rains amongst the fresh vegetation should show a higher percentage of green and a lower percentage of brown than those captured there in May, although we do not know at what season the latter were bred.

(*c*) *Nearly black.* Specimens of this group were taken in only six localities, and were only relatively common in certain southern districts, *i.e.*, Funa, Macina, Diafarabe and San, early in the season. They were not found at Diafarabe in September and their occurrence appears to be related to the occurrence of the bush fires.

(*d*) *Typical gregaria.* These naturally became more numerous after the arrival of the swarms, and were particularly abundant at Konna and Korienze. They were, however, quite common in the southern districts before the swarms appeared. The second 1932 generation of *gregaria* adults was only just beginning to appear at Diafarabe in September.

There is little correlation between general body colour and the marking of the inside of the hind femur. Nearly all the green, about half of the nearly black, and about 60 per cent. of the brown had the double marking. All but one of the typical *gregaria* had the single mark.

One of the many differences between the Diafarabe May and September specimens was that in the brown group only 36 per cent. had the double marking in May, while 80 per cent. had it in September.

TABLE XXV.

Colour Analysis of Solitary Locust Populations.
(Percentages.)

	Green	Nearly black	Brown	Typical *gregaria*
	%	%	%	%
Funa and Macina	23	8	43·5	25·5
Diafarabe (May)	11	7·5	64·5	17
Konna	1	0	11	88
Korienze	4	0	14	82
Sarafere	31	0	20	49
Dire	20	0	40	40
Kabara	30	2	19	49
Diafarabe (Sept.)	22·5	0	28·5	49

TABLE XXVI.

Frequency Distribution of E/F Ratios. Total Catches: Males.

	1·70 1·74	1·75 1·79	1·80 1·84	1·85 1·89	1·90 1·94	1·95 1·99	2·00 2·04	2·05 2·09	2·10 2·14	2·15 2·19	2·20 2·24	2·25 2·29	2·30 2·34	2·35 2·39
Funa and Macina		2	1	6	1	2	7	3						
Diafarabe (May)	4	9	20	22	27	24	35	23	11	2		1		
San, Benenigeni and Seyna ...			1	2		3	4	5	3	3	5	1		
Konna ...	1							6	15	13	3	2		
Korienze ...			2	2	1		3	5	15	22	20	5	7	
Sarafere ...		1	7	5	3	2	1	3	6	5	4	1		
Dire			10	5	3	4	3	4	3	9	1	1		
Horo			1		1	1			1	1				
Kabara ...			1		1	3	3	2	5	2				
Diafarabe (Sept.)		1	2	5	24	25	14	8	14	16	19	15		1

TABLE XXVII.

Frequency Distribution of E/F Ratios. Total Catches: Females.

	1·70 1·74	1·75 1·79	1·80 1·84	1·85 1·89	1·90 1·94	1·95 1·99	2·00 2·04	2·05 2·09	2·10 2·14	2·15 2·19	2·20 2·24	2·25 2·29	2·30 2·34	2·35 2·39	2·40 2·44
Funa and Macina		3	1	2	2	1	4	2	1						
Diafarabe (May)	1	5	19	20	18	14	18	20	11	9	4	1	1		
San, Benenigeni and Seyna ...				3		1		1		1	3	4	2		
Konna ...			1	1				1	5	12	12	8	4		
Korienze ...		1		2	6	1		1	3	8	5	10	1	3	
Sarafere ...		1	3	4	8	2			1	5	3	3	4		
Dire			1	6	8	3	1		2	4	4				
Horo					2				1	4	4				
Kabara ...			1	2	3	4	2		2	3	4	2			
Diafarabe (Sept.)				3	7	16	16	24	15	20	23	11	7	1	1

2. *Relative lengths of elytron and hind femur.*

(*a*) *E/F Ratio.*

A preliminary analysis of the Diafarabe populations is made by examining the frequency distribution of the E/F ratios; for this purpose the individual ratios are grouped in intervals of 0·5. As the E/F ratios of the males and females from the same catch differ considerably, the female ratio normally being the higher, the sexes

TABLE XXVIII.

Frequency Distribution of E/F Ratios, Diafarabe (May): Colour Groups.

	1·65 1·69	1·70 1·74	1·75 1·79	1·80 1·84	1·85 1·89	1·90 1·94	1·95 1·99	2·00 2·04	2·05 2·09	2·10 2·14	2·15 2·19	2·20 2·24	2·25 2·29	2·30 2·34
Males Green ...			3	4	4	5								
Black ...		1		4	5	1	2	1	1	1				
Brown ...		3	6	12	13	21	20	33	20	8	2			
T.G. ...							2	1	2	2			1	
Females Green ...				3	8	3	2			1				
Black ...				2			2	1	3		1			
Brown ...		1	4	13	11	11	2	7	7	4	5	2	1	
T.G. ...			1	1	1	4	8	10	10	6	3	2		1

TABLE XXIX.

Frequency Distribution of E/F Ratios, Diafarabe (May): Femoral Marking Groups.

	1·65 1·69	1·70 1·74	1·75 1·79	1·80 1·84	1·85 1·89	1·90 1·94	1·95 1·99	2·00 2·04	2·05 2·09	2·10 2·14	2·15 2·19	2·20 2·24	2·25 2·29	2·30 2·34
Females Double mark		1	4	19	20	17	6	8	10	1	1			
Single mark			1				5	5	5	4	7	3	1	1
Intermediates						1	3	5	5	6	1	1		
Males Double mark		4	8	20	17	16	5	4						
Single mark			1		1	9	14	28	22	11	2		1	
Intermediates					4	2	5	3	1					

are treated separately. The frequency distribution curves of the May and September Diafarabe collections are given in figs. 2 and 3, and the ratios, with those of collections from other localities, Tables XXVI and XXVII. The various locust populations are probably of very mixed origins and it is not surprising that the frequency distribution curves are usually discontinuous; normally they show two maxima.

(i) *Diafarabe May.*

The total frequency distribution curve for the females (Table XXVII) shows two distinct maxima indicating that there were at least two separate types present. The lower maximum, at 1·85–1·89, would seem to represent the true *solitaria* population, while the second, at 2·05–2·09, seems to represent a group of *transiens*, either the progeny of last year's swarms not yet fully reverted to the solitary or else the progeny of the indigenous *solitaria* developing *gregaria* characteristics.

TABLE XXX.

Frequency Distribution of E/F Ratios, Diafarabe (September): Colour Groups.

	1·75 1·79	1·80 1·84	1·85 1·89	1·90 1·94	1·95 1·99	2·00 2·04	2·05 2·09	2·10 2·14	2·15 2·19	2·20 2·24	2·25 2·29	2·30 2·34	2·35 2·39	2·40 2·44
Females														
Green ...			3		7	10	8	2	2		1			
Black ...														
Brown ...				7	9	5	11	4	1	2				1
T.G. ...						1	5	9	17	21	10	7	1	
Males														
Green ...	1	1	2	8	8	9	1		1					
Black ...														
Brown ...		1	3	16	16	3	1							
T.G. ...					1	2	6	14	15	19	15		1	

TABLE XXXI.

Frequency Distribution of E/F Ratios, Diafarabe (September): Femoral Mark Groups.

	1·75 1·79	1·80 1·84	1·85 1·89	1·90 1·94	1·95 1·99	2·00 2·04	2·05 2·09	2·10 2·14	2·15 2·19	2·20 2·24	2·25 2·29	2·30 2·34	2·35 2·39	2·40 2·44
Females														
Double mark			3	7	15	14	18	5	1	1	1			1
Single mark						1	6	9	14	21	10	6	1	
Intermediates					1	1		1	5	1		1		
Males														
Double mark	1	2	5	22	16	9	1		1					
Single mark				1	3	3	7	13	15	19	5		1	
Intermediates				1	6	2		1						

Table XXVIII shows an attempt to separate the two groups by colour differences. Though the green are nearly all displaced around the lower maximum and the typical *gregaria* (T.G.) round the upper, the brown are still heterogeneous with two maxima. There are very few black but there are indications that they also have two maxima and have higher ratios than the green.

In Table XXIX and fig. 5 the same specimens are separated into three groups according to the marking of the inside of the hind femur. It will be seen that the lower E/F ratios come almost entirely from the locusts with double marks, but the frequency distribution of even this group is discontinuous with two distinct maxima. Practically all the specimens with a single mark and the intermediate forms have high E/F ratios, the former tending to be the higher.

The total frequency distribution curve for the males (fig. 2) does not show two maxima but is distinctly asymmetric.

The colour analysis (Table XXVIII) indicates again that the greens have low ratios, the typical *gregaria* high, and that the browns are heterogeneous. The blacks have low ratios but their average (1·90) is rather above the green average (1·85).

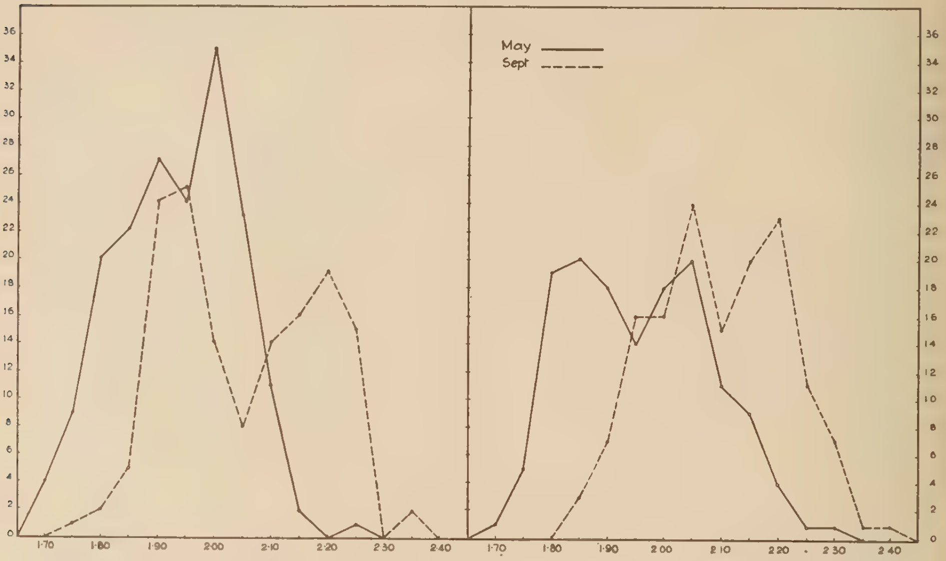

Fig. 2. Males. Fig. 3. Females.
Diafarabe, May and September, frequency distribution, total E/F ratios.

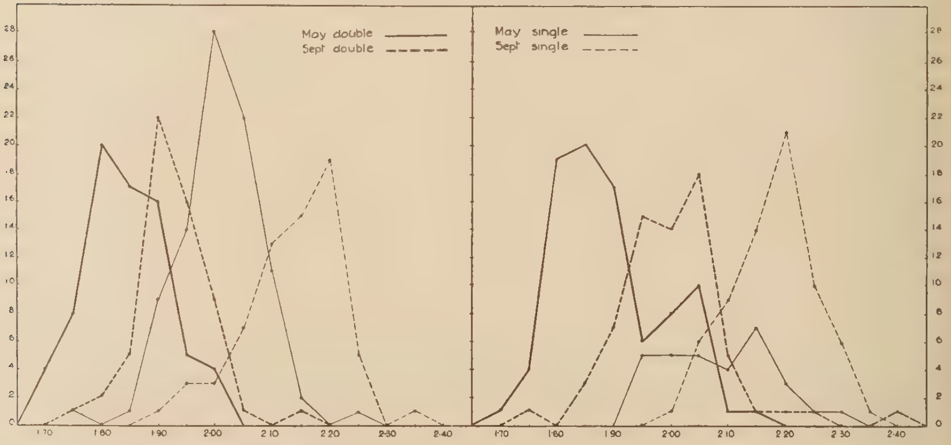

Fig. 4. Males. Fig. 5. Females.
Diafarabe, May and September,
frequency distribution, E/F ratios, femoral mark groups.

When these males are separated into the three groups by the marking of the hind femur (fig. 4), those with the double mark give a fairly normal distribution curve with a maximum of about 1·84 and those with the single mark another good curve with a maximum of about 2·02, while the few intermediates come rather below the divided group.

It is therefore concluded that at Diafarabe in May there were two main groups making up the total solitary locust population. These cannot be separated by general body colour but can be distinguished by their hind femoral marking. The group with the double mark probably consisted of fairly true *solitaria* with mean E/F ratios of 1·86 for the males and 1·91 for the females. The group with the single mark consisted of *transiens* of unknown status or origin with mean E/F ratios of 2·03 for the males and 2·09 for the females.

(ii) *Diafarabe—September.*

The total frequency distribution curve (fig. 3) of the females again shows two distinct maxima, both, however, being higher than the May maxima, *i.e.*, 2·05–2·09 and 2·20–2·24.

When the females are separated into their colour groups (Table XXX) it is found that the greens are displaced around the lower maximum and have a higher E/F ratio than the May females. The browns have two separate maxima as in May, but again the September ones have the higher ratios—1·95 and 2·05 as compared with 1·80 and 2·05. The typical *gregaria* are displaced around the upper maximum and again the E/F ratio is higher than in May.

In Table XXXI and fig. 5 where females are classified by the hind femoral marking it is seen that the catch can be separated fairly well into two main groups, but whereas in May the mean E/F ratio of those with a double mark was 1·19, in September it was 2·03 and the mean ratio of those with the single mark rose from 2·09 to 2·20.

The September males show the two maxima, *i.e.*, around 1·95 to 2·20 and the ratios are generally higher than with the May males.

When separated into their colour groups the lower maximum is occupied by the greens and browns and the upper by the typical *gregaria*. While the May green maximum is around 1·85, in September it had risen to around 1·95. In both collections the browns are grouped around 1·95, though the September specimens tend to be the higher. The typical *gregaria* increased from around 2·05 to 2·15–2·20.

When classified by the femoral markings the two main male groups show the same increase of the E/F ratio from May to September. The mean ratio of those with double mark rose from 1·86 to 1·94 and the ratios of those with the single mark from 2·03 to 2·15.

It is therefore concluded that at Diafarabe in September there were again two main groups making up the total solitary population, but these were by no means identical with the two May groups. The groups can be separated by general body colour, but as in May the femoral marks also serve to distinguish them (figs. 4, 5). In May there were *solitaria* and *transiens*, in September the *solitaria* were completely outnumbered by *transiens* and *gregaria*. It would appear that the total population had moved towards the gregarious phase during the rains ; but on the other hand it seemed fairly certain that a number of the September specimens came from gregarious hopper bands dispersed by the floods, as it is difficult to believe that the extensive loose bands observed on the west of the Diaka could have formed by association from the *solitaria* present in May. That these were *dissocians* would fit Zolotarevsky's hypothesis for the separation of the *transiens*. The September green locusts had a higher E/F ratio than the May specimens—if they were associating the colour would have changed to brown before the rise in the E/F ratio occurred.

(*b*) *The E/F ratio in relation to body size.*

The E/F ratio is normally used in locust work for distinguishing the phases, and when two collections give similar ratios it is concluded that they are identical in phase, except that it is realised that those with intermediate ratios—phase *transiens*—may be either *congregans* or *dissocians* that cannot be distinguished. A further analysis of the biometrics of the collections made in the Middle Niger seems to indicate that it is possible to separate locusts with similar E/F ratios into further groups. It is found for example that the Diafarabe May specimens of all E/F ratios are on the average definitely smaller than the Diafarabe September specimens with similar ratios. Although both sexes can be examined in this way, only the males are analysed here as the differences are most marked in this sex. In fig. 6 the average length of elytron (E) is plotted against the average length of the hind femur (F) for each 0·05 interval of the E/F ratios with the major ratios indicated by constant ratio lines.

It will be seen that in both the May and September collections E tends to increase directly with E/F, although in the September catch there is a final decrease at the highest E/F ratio. On the other hand F does not vary so greatly and as the E/F ratio rises from the lowest limits it first of all tends to decrease; it then increases around the 2·0 ratio and finally decreases in the upper ratios. This method of charting the E and F measurements, which may be termed a "phase-graph," would seem to be a valuable new method for the study of the phases of locusts and in this instance confirms biometrically that there is a fundamental difference between the locusts of the same E/F ratio caught at Diafarabe in May and September. As shown in figs. 8 and 9 the collections from eight other localities give the same form of phase-graph.

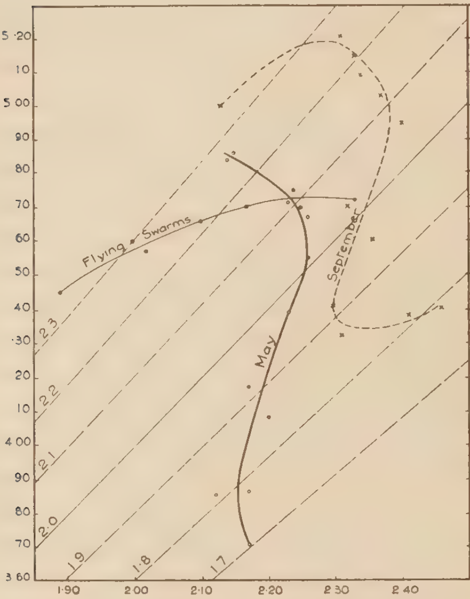

Fig. 6. Phase graph: Diafarabe, May and September, and flying swarms.

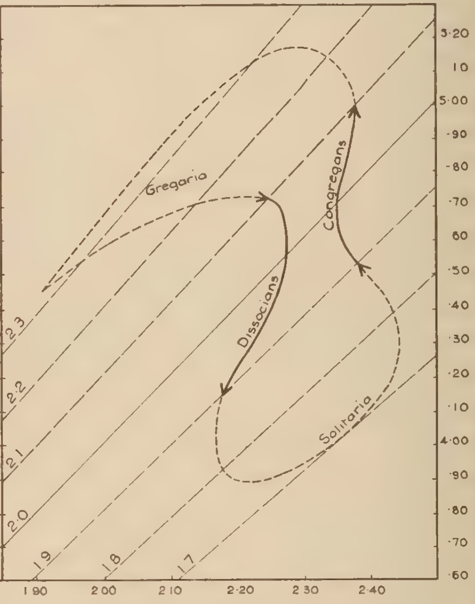

Fig. 7. Hypothetical complete phase graph.

There would appear to be two possible explanations of this phenomenon. Firstly, the series taken in May may represent the *dissocians* series and those taken in September the *congregans* series (or *vice versa*), or it may be a normal seasonal difference between dry and wet season generations. If the first suggestion be correct, it should be possible to build up a complete phase-graph showing the whole phase cycle from the measurements of cage-bred locusts, thereby giving a method for separating *congregans* from *dissocians* by simple measurement. The origins of the locusts taken in the middle Niger are so hypothetical and mixed that it is not worth while examining the results in great detail until the true explanation of the phase-graph is determined from controlled breeding experiments, but fig. 7 shows the possible form that the complete phase-graph may take.

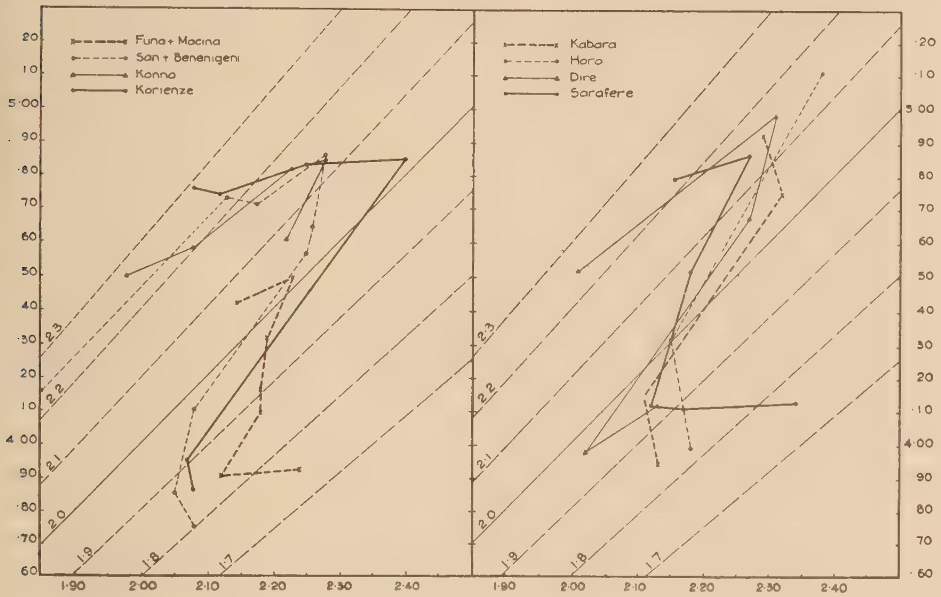

Fig. 8.

Fig. 9.

Phase Graphs.

3. *Sexual Dimorphism.*

Table XXXII shows the sexual dimorphism of each colour group and the two femoral marking groups of the Diafarabe May and September collections from the relative lengths of the male and female elytra. The degree of sexual dimorphism is expressed as the percentage of the average female elytron length to the average male elytron length. As has already been stated, the elytron length varies directly with the total body length. This relationship was determined from the paper of Johnston and Maxwell-Darling (^{8}), from whose data it was calculated that for all phases the total length approximately equals E × 1·25.

It is generally admitted that strong sexual dimorphism is one characteristic of the *solitaria* phase. Table XXXII shows that for the May specimens at any rate the colour groups arranged in order of decreasing sexual dimorphism remain in the same order as when arranged by E/F ratios. This table shows once more that with the green group and the femoral mark groups there is again a difference between the two generations, the September collection being nearer the *gregaria* than the May collection, as was previously indicated by the E/F ratios. The probable practical importance of the decrease of the sexual dimorphism in the gregarious phase is worth noting. In most solitary Acridid species the males are very markedly smaller than the females. With a gregarious insect that migrates in flying swarms the disadvantages of such an arrangement are fairly obvious, for after a day's migration of 50 to 100 miles there would probably be a complete segregation of the sexes by the time the swarm settled for the night if the females were larger and, presumably, stronger in flight.

The table shows that as the change from *solitaria* to *gregaria* occurs the males increase in size to a relatively greater degree than the females decrease. It also shows again how the May specimens are generally smaller than the September specimens.

TABLE XXXII.

Sexual Dimorphism, Diafarabe Collections.

Colour groups	May			September		
	Male	Female	Sexual dimorphism	Male	Female	Sexual dimorphism
Green	4·07	5·41	133	4·59	5·41	118
Nearly black	4·06	5·07	125	—	—	—
Brown	4·34	5·15	119	4·50	5·39	120
T.G.	4·71	5·12	109	5·08	5·36	106
Double femoral mark	3·97	5·19	131	4·49	5·39	120
Single femoral mark	4·58	5·14	112	5·07	5·35	106

4. *Colour of Hind Tibia.*

As quoted above Uvarov and Zolotarevsky record that pink hind tibiae are a characteristic of the *solitaria* phase.

Table XXXIII shows another fundamental difference between the Diafarabe May and September locusts. Whereas in May 72 per cent. of the green males had

TABLE XXXIII.

Colour of Hind Tibiae in relation to General Body Colour and Hind Femoral Marking (Males). Percentage of Specimens with Pink Tibiae.

Locality	Colour groups				Femoral marking groups	
	Green	Nearly black	Brown	T.G.	Double	Single
Diafarabe (May)	72	57	27	0	66	8
Mopti	—	—	—	0	—	0
Benenigeni, San and Seyna ...	50	100	14	0	83	0
Fotoma	—	—	—	0	—	0
Konna	—	—	25	2	100	4
Korienze	100	—	18	0	100	0
Sarafere	100	—	75	0	89	0
Dire	100	—	100	0	100	0
Horo	100	—	50	0	66	0
Diafarabe (Sept.)	0	—	0	0	0	0

pink tibiae, in September none of the 136 collected had pink, 97 per cent. had yellow, and 3 per cent. were intermediate. According to Johnston and Maxwell-Darling this indicates that the September *transiens* were *congregans*. Taking pink hind tibiae as an indication of the *solitaria* phase the general body colour groups are arranged in the following order :—green, nearly black, brown, typical *gregaria* ; which order agrees with that obtained from the E/F ratios (Table XXVIII) and sexual dimorphism (Table XXXII) of the colour groups.

As shown in the second half of Table XXXIII all specimens with pink tibiae have the double hind femoral marking, but all specimens with double marking do not have pink tibiae.

5. *Summary of Diafarabe Collections.*

The differences in colour, markings, and measurements between the two collections of *Locusta* taken at Diafarabe in May and September may be summarised as follows :—

General body colour. May : all four colour groups present, *i.e.*, green, nearly black, brown and typical *gregaria* ; 36 per cent. of the browns with double femoral marking. September : nearly black group completely absent ; marked increase in green and typical *gregaria* groups ; 80 per cent. of the browns with double femoral marking.

E/F Ratios. May : two distinct but overlapping populations distinguished by double and single hind femoral marking. September : two similar populations present but each with a higher E/F ratio than the May populations.

E/F Ratios in relation to body size. By means of the phase-graph it is shown that the May specimens differ from the September specimens of similar E/F ratios by being generally smaller in length of elytron and hind femur.

Sexual Dimorphism. May : females of green colour group 133 per cent. size of males. September : females of green colour group 118 per cent. size of males.

Colour of Hind Tibiae. May : high percentage of males with pink hind tibiae. September : no males with pink hind tibiae.

6. *Conclusions.*

Owing to the very mixed collections made in the field and the quite unknown origins of the specimens taken at Diafarabe, it is dangerous to make definite conclusions from the above data, but it is interesting to see whether there are any indications of the phase status of the two collections or whether the differences are due only to season.

It is considered that the middle Niger area, especially Diafarabe, lies within the distribution area of *solitaria* ; it is equally certain that this locality has been invaded annually, at least since 1928, by flying swarms from which stragglers are certain to have fallen out, giving rise to the *dissocians* phase. The absence of nearly black specimens in September was almost certainly a seasonal effect. The production of this colour in the dry season is probably related to the abundance of black burnt vegetation which is completely absent when the September generation is bred. Considering the number of swarm stragglers present in September the number of green specimens collected in the second period was surprisingly high but the browns were relatively scarce. This is probably explained by the abundance of green vegetation at this time of the year and possibly to the fact that when dissociation is taking place the *gregaria* change to green very rapidly (Zolotarevsky).

Taking the double femoral marking as a characteristic of the *solitaria* phase the September browns were nearer this phase than the May browns, though they did not have the pink tibiae of the earlier generation. The September greens, on the other hand, were nearer *gregaria* than the May greens, according to E/F ratio, sexual dimorphism and colour of hind tibiae.

The following is a suggested explanation which, although it cannot yet be proved, serves as a reasonable working hypothesis. The phase series, *solitaria*→*congregans*→*gregaria* differs biometrically and in marking from the series *gregaria*→*dissocians*→*solitaria*. The two phase series that have been distinguished in the phase-graph may be termed the lower and upper phase series, since the members of the one are smaller than the members of the other. Examination of the data suggests that the lower series represents the *dissocians* series and the upper the *congregans*, although some of the facts do not agree with previous opinions. In May all stages of the *dissocians* series were present, with *solitaria* and *dissocians* dominant. The *solitaria* were probably at least partly the indigenous population, and the *dissocians* were probably the progeny of the previous (1931) wet season's swarm stragglers. During the rains the series changed direction; both the *solitaria* and the *dissocians* moved up the *congregans* series, forming two distinct steps in this series. The upper step was probably rather mixed and almost certainly included some *dissocians* offspring of 1932 swarm stragglers.

The following are therefore the hypothetical characters of the various phases :—

Phase solitaria.

(i) Colour variable but especially green and nearly black.
(ii) Black streaks on upper surface of pronotum absent.
(iii) Low E/F ratio, males average 1·85, females average 1·90.
(iv) Strong sexual dimorphism ; females 130 per cent. length of males.
(v) Male hind tibiae pink.
(vi) Two black marks on inside of hind femur.

Phase gregaria.

(i) Colour brown, males yellow when sexually mature.
(ii) Two black streaks on upper surface of pronotum.
(iii) High E/F ratio ; males average 2·17, females average 2·20.
(iv) Slight sexual dimorphism ; females 106 per cent. length of males.
(v) Male hind tibiae variable in colour but not pink.
(vi) One large black mark on inside of hind femur.

Phase congregans.

(i) Colour variable, especially green and brown.
(ii) Black streaks on upper surface of pronotum frequently present.
(iii) Intermediate E/F ratio.
(iv) Sexual dimorphism intermediate but less than in phase *dissocians*.
(v) Male hind tibiae usually as in phase *gregaria*.
(vi) One or two black marks on inside of hind femur.
(vii) Average lengths of elytron and femur somewhat longer than in phase *dissocians*.

Phase dissocians.

(i) Colour variable.
(ii) Black streaks on upper surface of pronotum frequently present.
(iii) Intermediate E/F ratio.
(iv) Sexual dimorphism intermediate.
(v) Male hind tibiae pink or variable.
(vi) One or two black marks on inside of hind femur.
(vii) Average lengths of elytron and femur somewhat shorter than in phase *congregans*.

If the above be a correct interpretation then a representative collection of *transiens* may be determined as *congregans* or *dissocians* as follows :—If most males with double femoral marking have pink hind tibiae—phase *dissocians* ; if males with double femoral marking have not pink hind tibiae—phase *congregans*.

Or by measurement :

When E/F=1·90 E x F<9·75—phase *dissocians*
E x F>9·75— ,, *congregans*
E/F=2·00 E x F<10·40— ,, *dissocians*
E x F>10·40— ,, *congregans*
E/F=2·10 E x F<11·00— ,, *dissocians*
E x F>11·00— ,, *congregans*

Or, when E of females with double femoral marking exceeds 125 per cent. of E of males with similar marking—phase *dissocians* ; when less than 125 per cent.—phase *congregans*.

3. Flying Swarms.

Specimens from only three swarms and some stragglers were examined and measured, though more samples have been preserved. The important biometric details are given above and the frequency distribution of the E/F ratios in Table XXXIV. The average E/F ratios are compared in Table XXXV with the average male and female ratios of the first five generations of *gregaria* in Nigeria.

TABLE XXXIV.

E/F Ratio ; Flying Swarms and Swarm Stragglers.

	1·70 1·74	1·75 1·79	1·80 1·84	1·85 1·89	1·90 1·94	1·95 1·99	2·00 2·04	2·05 2·09	2·10 2·14	2·15 2·19	2·20 2·24	2·25 2·29	2·30 2·34	2·35 2·39	2·40 2·44
Males															
Swarm 1 ...							1	1	6	10	4	2	1	1	
Swarm 8 ...							3	6	5	7	12	4		1	
Swarm 14 ...								1	7	7	3	2			
Mopti ...							1	1	1	2		1			
Benenigeni ...							1	1	1	2	2	1			
Fotoma ...								1	1	3	5	2		1	
Konna ...	1							6	12	15	4	2			
Miscellaneous											1				
Total ...	1						6	17	33	46	31	14	1	3	
Females															
Swarm 1 ...							1	2	4	3	8	7			1
Swarm 8 ...									1	7	3	3	2		
Swarm 14 ...									1	4	6	6	3		
Mopti ...									1	3	4	3			
Benenigeni ...								1		1	1		1		
Fotoma ...									2		4	6			
Konna ...			1	1				1	5	12	12	8	4		
Miscellaneous									1	1					
Total ...			1	1			1	4	15	31	38	33	10		1

The Nigerian figures were obtained from numerous small samples of many swarms from various parts of the country, and although they may not be quite true averages it is seen that there was apparently little significant difference between the E/F ratios of the 1929 Nigerian swarms and the 1932 middle Niger swarms.

TABLE XXXV.

Flying Swarms: Average E/F Ratios.

Date	Generation	Territory	Males	Females
1929–30	4	Nigeria	2·16	2·28
1930	5	,,	2·23	2·21
1930–31	6	,,	2·17	2·20
1931	7	,,	2·14	2·21
1931–32	8	,,	2·15	2·11
1932	8	Middle Niger	2·17	2·20

The phase-graph of the flying swarms has been inserted in fig. 6. It will be seen that it seems to link up much more closely with the lower series than with the upper, and therefore these *gregaria* although still remaining in swarms were tending towards the *dissocians* phase.

The writer has not available the actual E and F measurements of the Nigerian swarms and consequently cannot compare them with those of the middle Niger by means of the phase-graph.

TABLE XXXVI.

E x F, Flying Swarms and Stragglers (Males).

E/F Ratio	2·00–2·09	2·10–2·19	2·20–2·29	2·30–2·39
Swarm 1	10·19	10·52	10·32	9·32
,, 8	10·49	10·27	9·28	
,, 14	11·04	10·18	10·05	7·36
Mopti	10·97	11·01	8·76	
Benenigeni	10·10	10·54	9·48	
Fotoma	9·22	10·50	10·18	8·39
Konna	10·26	10·92	9·37	
Total swarms ...	10·51	10·41	9·65	8·64
Total stragglers ...	10·26	10·85	9·63	8·39
Total E	4·63	4·81	4·64	4·48
Total F	2·24	2·23	2·08	1·91
Total E x F ...	10·37	10·73	9·65	8·56

In Table XXXVI the samples of flying swarms and stragglers are treated separately as regards E x F to see whether the latter show more signs of dissociation than the flying swarms, but taken with the data in Table XXXIV it will be seen that there is no significant difference.

The relative percentage of parasitism in swarms and stragglers was not determined, but it would be most instructive to determine whether parasitised *gregaria* tend to fall out of the swarm and thereby prevent a rapid increase of parasites in the abundant host material.

4. Other Solitary Populations.

TABLE XXXVII.

E/F Ratio; Green Colour Group, Males.

	1·70 1·74	1·75 1·79	1·80 1·84	1·85 1·89	1·90 1·94	1·95 1·99	2·00 2·04	2·05 2·09	2·10 2·14	2·15 2·19
Funa and Macina ...		1		5						
Diafarabe (May) ...		3	4	4	5					
San				1		3	1			
Seyna										1
Korienze					1					
Sarafere		1	3	2	3	1		1		
Dire			2		2	2				
Horo			1							
Kabara			1			1				
Diafarabe (Sept.) ...		1	1	2	8	8	9	1	1	

TABLE XXXVIII.

E/F Ratio; Nearly Black Colour Group, Males.

	1·70 1·74	1·75 1·79	1·80 1·84	1·85 1·89	1·90 1·94	1·95 1·99	2·00 2·04	2·05 2·09	2·10 2·14	2·15 2·19
Funa and Macina ...			1							
Diafarabe (May) ...	1		4	5	1	2	1	1	1	
San				1						

TABLE XXXIX.

E/F Ratio ; Brown Colour Group, Males.

	1·70 1·74	1·75 1·79	1·80 1·84	1·85 1·89	1·90 1·94	1·95 1·99	2·00 2·04	2·05 2·09	2·10 2·14	2·15 2·19	2·20 2·24	2·25 2·29	2·30 2·34
Funa and Macina				2		2	2	2					
Diafarabe (May)	3	6	12	13	21	20	33	20	8	2			
Miyatiki ...										1			
San							1	1					
Benenigeni ...							1		1				
Seyna								1			1		
Korienze ...			2	2						3	3	2	1
Sarafere ...			4	3		1							
Dire			8	5	1	2	2	1					
Koiretago ...					1								
Horo					1	1							
Kabara					1	2	1						
Diafarabe (Sept.)			1	3	16	16	3	1					

TABLE XL.

E/F Ratio ; T.G. Colour Group, Males.

	1·90 1·94	1·95 1·99	2·00 2·04	2·05 2·09	2·10 2·14	2·15 2·19	2·20 2·24	2·25 2·29	2·30 2·34	2·35 2·39
Funa and Macina ...	1		5	1						
Diafarabe (May) ...		2	1	2	2			1		
San			1	1	2		2			
Seyna				1						
Korienze			3	5	15	19	17	3	6	
Sarafere			1	2	6	5	4	1		
Dire			1	3	3	9	1	1		
Horo					1	1				
Kabara			2	2	5	2				
Diafarabe (Sept.) ...		1	2	6	14	15	19	15		1

TABLE XLI.

E/F Ratio; Green Colour Group, Females.

	1·70 1·74	1·75 1·79	1·80 1·84	1·85 1·89	1·90 1·94	1·95 1·99	2·00 2·04	2·05 2·09	2·10 2·14	2·15 2·19	2·20 2·24	2·25 2·29
Funa and Macina ...		1			1		1					
Diafarabe (May) ...			3	8	3	2			1			
Miyatiki	1											
Mopti			1									
San				1								
Konna			1									
Korienze				2	2							
Sarafere		1	2	3	5	2						
Dire				5	3	1						
Koiretago				1		1						
Horo					1							
Kabara			1	2	2	2	1		1			
Diafarabe (Sept.) ...				3		7	10	8	2	2		1

TABLE XLII.

E/F Ratio; Nearly Black Colour Group, Females.

	1·80 1·84	1·85 1·89	1·90 1·94	1·95 1·99	2·00 2·04	2·05 2·09	2·10 2·14	2·15 2·19
Diafarabe (May)	2			2	1	3		1
San				1				
Horo				1				

TABLE XLIII.

E/F Ratio; Brown Colour Group, Females.

	1·70 1·74	1·75 1·79	1·80 1·84	1·85 1·89	1·90 1·94	1·95 1·99	2·00 2·04	2·05 2·09	2·10 2·14	2·15 2·19	2·20 2·24	2·25 2·29	2·30 2·34	2·35 2·39	2·40 2·44
Funa and Macina		2	1	1	1	1	3	1	1						
Diafarabe (May)	1	4	13	11	11	2	7	7	4	5	2	1			
Benenigeni								1							
San ...				1							1	1			
Seyna ...												1			
Konna ...				1					1						
Korienze		1			4	1									
Sarafere			1	1	3										
Dire ...			1	1	5	1	1		1						
Horo ...					1										
Kabara ...					1	2	1								
Diafarabe (Sept.)					7	9	5	11	4	1	2				1

TABLE XLIV.

E/F Ratio; T.G. Colour Group, Females.

	1·75 1·79	1·80 1·84	1·85 1·89	1·90 1·94	1·95 1·99	2·00 2·04	2·05 2·09	2·10 2·14	2·15 2·19	2·20 2·24	2·25 2·29	2·30 2·34	2·35 2·39
Funa and Macina			1			1	1						
Diafarabe (May)	1	1	1	4	8	10	10	6	3	2		1	
San										1		1	
Seyna										1			
Korienze ...							1	3	8	5	10	1	3
Sarafere ...								1	5	3	3	4	
Dire							1	1	5	3			
Horo								1	4	4			
Kabara								1	3	4	2		
Diafarabe (Sept.)						1	5	9	17	21	10	7	1

TABLE XLV.

E/F Ratio; Double Femoral Mark Group, Males.

	1·70 1·74	1·75 1·79	1·80 1·84	1·85 1·89	1·90 1·94	1·95 1·99	2·00 2·04	2·05 2·09	2·10 2·14	2·15 2·19
Diafarabe (May) ...	4	8	20	17	16	5	4			
San			1	2		3				
Korienze			2	2	1					
Sarafere		1	7	5	3	2		1		
Dire			9	4	3	4	2	1		
Koiretago					1					
Horo			1							
Kabara			1		1	3	1			
Diafarabe (Sept.) ...		1	2	5	22	16	9	1		1

TABLE XLVI.

E/F Ratio; Single Femoral Mark Group, Males.

	1·75 1·79	1·80 1·84	1·85 1·89	1·90 1·94	1·95 1·99	2·00 2·04	2·05 2·09	2·10 2·14	2·15 2·19	2·20 2·24	2·25 2·29	2·30 2·34	2·35 2·39
Diafarabe (May)	1		1	9	14	28	22	11	2		1		
Miyatiki ...									1				
San						3	2	2		2			
Seyna							2		1	1			
Korienze ...						3	5	15	22	20	5	7	
Sarafere ...							2	6	5	4	1		
Dire						1	3	3	8	1	1		
Horo								2	2				
Kabara						2	1	5	1				
Diafarabe (Sept.)				1	3	3	7	13	15	19	5		1

TABLE XLVII.

E/F Ratio; Double Femoral Mark Group, Females.

	1·70 1·74	1·75 1·79	1·80 1·84	1·85 1·89	1·90 1·94	1·95 1·99	2·00 2·04	2·05 2·09	2·10 2·14	2·15 2·19	2·20 2·24	2·25 2·29	2·30 2·34	2·35 2·39
Diafarabe (May)	1	4	19	20	17	6	8	10	11					
Miyatiki ...	1													
San				2		1								
Korienze ...		1		2	6	1								
Sarafere ...		1	3	4	8	2								
Dire			1	6	7	2	1		1					
Koiretago ...				1		1								
Horo					2	1				1	1			
Kabara ...			1	2	3	3			1					
Diafarabe (Sept.)				3	7	15	14	18	5	1	1	1		1

TABLE XLVIII.

E/F Ratios; Single Femoral Mark Group, Females.

	1·75 1·79	1·80 1·84	1·85 1·89	1·90 1·94	1·95 1·99	2·00 2·04	2·05 2·09	2·10 2·14	2·15 2·19	2·20 2·24	2·25 2·29	2·30 2·34	2·35 2·39
Diafarabe (May)	1				5	5	5	4	7	3	1	1	
San			1							1	1	1	
Seyna										1	3		
Korienze ...							1	3	7	4	10	1	3
Sarafere ...									3	3	2	3	
Dire							1		4	3			
Horo								1	2	2			
Kabara ...									1	3	1		
Diafarabe (Sept.)						1	6	9	14	21	10	6	1

TABLE XLIX.

Femoral Marking and Tibial Coloration; Percentage of each Sex.

Locality	Males				Females	
	Double femoral mark			Single femoral mark	Double femoral mark	Single femoral mark
	Pink tibiae	Yellow tibiae	Total			
Diafarabe (May) ...	27	8	43	47	64	21
Mopti			0	100	8	85
Benenigeni			0	100	25	25
San	33	7	40	60	43	57
Seyna			0	100	0	100
Fotoma			0	100	0	100
Konna	2		2	98	11	69
Korienze	6		6	94	23	71
Sarafere	45		50	47	53	34
Dire	56		56	44	58	29
Horo	25		37	50	33	47
Kabara	35		35	53	45	18
Diafarabe (Sept.) ...		44	45	46	43	50

5. General Conclusions.

Table XLIX clearly shows how many of the specimens collected at Diafarabe in September differed fundamentally from those taken elsewhere. It has already been suggested that these belonged to the *congregans* series and it is therefore concluded that this was the only area where representatives of this phase were collected in any number. A few *congregans* were probably included in the collections from Korienze, Dire, Horo and Kabara. The Diafarabe September specimens were the only ones taken belonging to the 1932 F_3 generation or that had developed under flood conditions, and it therefore appears that under certain conditions, probably connected with flooding, this is the generation most likely to develop into phase *gregaria*.

X. ASSOCIATION AND THE DEVELOPMENT OF PHASE *GREGARIA*.

1. General Considerations.

It is now generally accepted that by overcrowding *solitaria* hoppers may be induced to develop *gregaria* characteristics, and there is also some evidence to show that forced activity causes the same change. Overcrowding may arise from four primary causes: (i) decrease in size of habitat, (ii) increase in locust population, (iii) synchronisation of breeding, and (iv) migration.

A decrease in size of the habitat may result from several eventualities. It has been shown that the *solitaria* are confined to very few natural habitats and areas of suitable grassland may be reduced by rising floods gradually forcing the mobile insect fauna towards high land, by drought gradually driving the insects to hollows and depressions carrying more luxuriant vegetation, or by bush fires which will act in the same direction though much more rapidly. Fires burn so fast that when they reduce the size of the habitat they act against immediate overcrowding by the destruction of much insect life and it is probable that only the winged adults escape.

Increase in population may also be due to several causes—abundance of food, scarcity of parasites and predators, and congenial climatic conditions, permitting an additional annual generation. An instance of such a natural increase in population has been described by Johnston & Maxwell-Darling (^{8}). In April 1926, incipient swarms were observed on the Red Sea coast near Port Sudan, and there was little doubt that this development of phase *congregans* was due to an additional number of generations of the *solitaria* permitted by unusually persistent green vegetation as a result of exceptional winter rainfall. Although this is the only instance recorded of the formation of incipient swarms the writer considers that it is very unlikely that such a natural increase can be the sole cause of association leading to phase *gregaria* ; it is far more likely to be a valuable preliminary, and the final transformation only occurs when the habitat is reduced concomitantly or subsequently.

Synchronisation of breeding may result in concentrations without a decrease of habitat or an actual increase in population. Association is much more likely to occur if all the *solitaria* hoppers in a habitat hatch together and not spasmodically over a period of weeks. As has already been explained such a synchronisation may be initiated by sudden climatic changes.

The possible influence of what may be termed involuntary migration, due to the habits of adult *solitaria* always flying down wind, has already been discussed, but it is unlikely that this factor plays an important part in the normal development of the gregarious phase.

It is perhaps inadvisable always to consider the transition from *solitaria* to *gregaria* as an unusual occurrence only happening when some outside influences cause forced concentrations. It may be more enlightening to think in quite different terms. Why do the *solitaria* not multiply sufficiently each year to produce the dense population that induces swarming ? In other words should we attempt to elucidate the causes of overcrowding that occur say every ten or twenty years or should we try to explain why such overcrowding does not occur regularly ?

2. Populations : Solitaria versus Gregaria.

Some of the causes of the transition from *solitaria* to *gregaria* have been explained, though little is yet known of the precise physiological processes that result in this change. It is presumed that a large number of *solitaria* were driven into forced concentrations during the years 1926 to 1928 ; as a result phase *gregaria* was produced and the offspring of these relatively few *solitaria* migrated, generation by generation, over the face of Africa. By 1932 there were present innumerable swarms, each made up of countless individuals, throughout the invasion area. All these individuals were the offspring of the middle Niger *solitaria*. The phase theory explains generally how swarm formation occurs, but does it explain how this remarkable multiplication takes place ?

The population of all living organisms is regulated by the following factors, (i) interspecific relationships, (ii) intraspecific relationships, and (iii) the inanimate environment. Without the operation of one or more controlling factors the population of any species, whatever its phase, will increase in a very short time to vast proportions. Some of the more important factors may be examined to see their differential effect on the *solitaria* and *gregaria* of Acrididae.

Interspecific Relationships.

Beneficial.—So far as is known no other species are directly beneficial to either phase.

Harmful.—There are three principal classes of natural enemies of both phases. In the first place, *birds*, the controlling influence of which appears greater on the population of solitary Orthoptera scattered over the countryside than on locusts concentrated in certain localities. Thus, if we presume that over an area of 100 miles square the population density of *solitaria* is 1,000 per square mile (a population that would give a T.O.I. index of 31) and the population density of the bird predators is 10 per square mile and that each bird normally devours 10 *solitaria* per diem, then during 10 days the *solitaria* population will be reduced from 10 million to nil, if we ignore any breeding of the locusts. If on the other hand, we presume that all these *solitaria* congregate and form a moving swarm 100 yards long and 10 yards wide and that this swarm passes across a similar area with the same bird population, taking one day to traverse the 100 miles, the birds will probably be attracted from a belt one mile wide and therefore only 1,000 birds will attack the swarm per diem. If the swarm continues for 10 days through a similar environment the population will be reduced by only 1 per cent., from 10 million to 9,900,000. This comparison does not take into account various complicating factors, *e.g.*, that some species of birds only attack flying Orthoptera and that the undisturbed *solitaria* fly very little and that swarms sometimes accumulate numbers of bird followers.

Though it would appear that *parasitic insects* and *fungi* tend to act more vigorously against swarms than against solitary individuals, it is probable that a high percentage of infected locusts fall out of a swarm so that infection is left behind. If this were not so a migrating swarm would rapidly accumulate heavy infection.

Intraspecific Relationships.

Beneficial.—It is probable that in a swarm 100 per cent. of the females are fertilised, but it is doubtful if the percentage is nearly so high amongst widely scattered individuals. It is thought that there are three generations of *solitaria* per annum in the south-western province of the middle Niger, whereas the *gregaria* normally have only two. Therefore the natural increase of the latter is markedly less rapid if the number of eggs laid by the females of the two phases is the same.

Harmful.—*Locusta* are not cannibals except for attacking maimed individuals.

Inanimate Environment.

Owing to their migratory habits the flying swarms are well adapted to seek out optimum climatic conditions, abundant food supply, etc., while they are equally well able to escape such catastrophes as fire and flood. The less mobile *solitaria* may have to pass through very critical times, such as a long dry season, and cannot escape far from the bush fires and rising floods.

The above summary indicates some of the factors that differentiate between the *solitaria* and *gregaria* phases and the effect or absence of which assists the spectacular multiplication of locust swarms.

3. The Origin of the Present Outbreak.

There is no evidence at all of any swarms of *Locusta* being present in West Africa before July 1928, but in that year the swarms observed were of considerable dimensions and it is most unlikely that the transformation from *solitaria* to *gregaria* took place during a single generation. It is far more probable that association had been proceeding gradually during the previous generations and we should therefore look for the cause of the initial change back in 1927 or even 1926. It has been clearly shown in Sections II, A. and III, C. that during these two years both the floods and rains in the south-western area were unusual. Zolotarevsky (17) has also called attention to these irregularities. We may now examine the sequence of events from 1925 to 1928 in an attempt to recapitulate the events that led up to the invasion of the greater part of Africa.

In 1926 in the southern area the rains set in unusually early and very suddenly, and while the early rains were abnormally heavy the middle rains were well below average. In the following year the rains were similar, though none of the abnormalities were so marked. In 1928, although the rains were again rather early, they set in spasmodically and were never very intense.

In 1926, therefore, we may presume that the *solitaria* population of the *Vetiveria* plains commenced to oviposit more or less simultaneously about the end of May. With the heavy rainfall the eggs would tend to hatch together and the vegetation would be sufficiently abundant to supply ample food. That year the flood was low and probably left areas exposed, so that the *solitaria* were able to breed without interruption. During this year the *solitaria* had good facilities for normal multiplication and in addition the breeding of the individuals was put into step by the sudden climatic changes. The year 1926 was therefore a year when excellent material for the formation of phase *congregans* was built up. In 1927 the *solitaria* found a repetition of similar climatic and flood conditions and the tendency towards the *congregans* would be intensified, in fact, by August of this year incipient swarms had probably collected together. Finally in 1928 the first generation of hoppers collected in more and more definite bands and when they matured in July the first flying swarms left the middle Niger.

Zolotarevsky considers the actual outbreak centres to be located at the edge of the flood area, especially to the north-west of Diafarabe. As a result of the present survey the writer believes them to be the main *Vetiveria* plains situated on the intermediate levels of the inundated area.

In the south-western area the time of maximum flood coincides with a period of hopper activity ; in the central and north-eastern areas the flood comes during the dry season, when it is presumed the *solitaria* are mainly in the adult stage. The observations taken at Diafarabe seem to indicate that the rising floods tend to cause the development of phase *congregans*, and it is therefore considered that swarm formation is most likely to occur in the south-western area. From the present limited survey it is considered that the most extensive *Vetiveria* areas lie in the vicinity of Diafarabe, so that this district, where the first hopper bands were reported in 1928, is probably the most important centre to be studied and one to be kept under continuous observation when the migratory locust has been forgotten in other parts of its invasion area.

APPENDIX I.

Swarms of Locusta migratoria migratorioides.

*=no specimens identified.

Swarm No.	Date	Locality	Type of swarm	Mode of flight	Direction to which swarm was flying	Weather conditions	Wind direction and force	Sex ratio	Age of locusts	% age males yellow	E/F		Sexual dimorphism	Ovarian development	Time
											Male	Female			
1.	April 14	Bamako	L.D.	Drifting	O										All day
2.	May 28	Diafarabe	S.D. (2 ml. long)	Settling or drifting	W	Bright sun	E.4	278	old	2	2·18	2·20	105		14–15
3.*	May 31	10 ml. E. of Miyatiki	L.C. (about 20 ml. long)		? N										17
4.*	June 3	R. Niger, 20 ml. E. of Diafarabe	M.		S.W.										17
5.	June 7	Mopti	M	Drifting	From S.W. to S.E.			110	medium	2				Nil.	16–18
6.*	June 9	15 ml. W. of Mopti	L		N.W.										9–11
7.	June 9	Mopti	L.C.		N.W.	Bright sun	S.W.3.5								9–12
8.	June 11	Mopti	L.D.	Drifting	N.W.		N.0–3	172	old	20				Nil.	15–19
9.	June 13	R. Bani, 8 ml. S. of Mopti	M.D.	Drifting settling & feeding	N.E.		S.S.W.0 3	49	old	3	2·16	2·21	108	Nil.	12
10.*	June 13	R. Bani, 16 ml. S. of Mopti	S.C. (1 x ¼ ml.)	Some settling	W.N.W.	Bright sun	E.S.E.2								15

APPENDIX I.—*continued.*

Swarm No.	Date	Locality	Type of swarm	Mode of flight	Direction to which swarm was flying	Weather conditions	Wind direction and force	Sex ratio	Age of locusts	% age males yellow	E/F		Sexual dimorphism	Ovarian development	Time
											Male	Female			
11.*	June 15	Sofara	M.	Flying fast	S.W.	Bright sun	N.E.3								11
12.*	June 16	R. Bani, 10 ml. S. of Djenne	L.	Flying fast	S.W.	Dull	N.E.4								15
13.*	June 18	Benenigeni	L.		N.E.										
14.*	June 23	8 ml. N.E. of San	L.												17
15.	June 23 & 24	San	L. (2x1 m) C.	Circling settling feeding	S.E.	Bright sun	N.W.O.5	182			2·16	2·21	106		17 hr. 23rd to 9 hr. 24th
16.*	June 25	Benenigeni			S.W.										
17.	June 27	R. Bani, between Baramadougou & Toura	L.C.	Drifting & settling on sandbank	N.N.W.	Bright sun	S.W.3	142		19					
18.	June 29	Seyna	S.		E.N.E.		W.S.W.1	100		0					9
19.*	June 30	Konna	S.		E.N.E.	Bright sun	S.W.1								16
20.	June 30 July 1	Nr. Konna Mopti	L.	Flying down R. Bani	N.			150		38					17 13

APPENDIX I.—*continued.*

Swarm No.	Date	Locality	Type of swarm	Mode of flight	Direction to which swarm was flying	Weather conditions	Wind direction and force	Sex ratio	Age of locusts	% age males yellow	E/F		Sexual dimorphism	Ovarian development	Time
											Male	Female			
21.	July 2	Mopti	M.	Drifting, later divided into 4 swarms	N.		S.1	10		18					
22.*	July 8	San	L.												
23.	July 8	Mopti	S.							100				Full	17
24.	July 8	8 ml. S.E. of Mopti			N.										
25.*	July 10	N.E. of Konio	M.												18
26.*	July 10	E. of Konio	M.												18
27.*	July 12	10 ml. S.W. Konna	M.D.		N.										17
28.*	July 13	R. Koli-Koli between Konna & Sindigi	M.		? E										12
29.*	July 13	Korienze	(possibly same swarm)												
30.*	July 14	E. Lake Korienze	M.		? E										10

APPENDIX I.—*continued.*

Swarm No.	Date	Locality	Type of swarm	Mode of flight	Direction to which swarm was flying	Weather conditions	Wind direction and force	Sex ratio	Age of locusts	%age males yellow	E/F		Sexual dimorphism	Ovarian development	Time
											Male	Female			
31.*	July 17	Nr. Korienze	S.		N.E.										
32.*	July 19	S.E. Lake Korienze	L.		N.W.										16
33.*	July 20	S. Lake Korienze	M.												
34.*	July 20	S. Lake Debo	S.												
35.	July 24	S.E. Sarafere	S.	Drifting	N.E.	Bright sun	S.W.4								9
36.*	July 25	W. Sarafere	S.D.		0										
37.	July 26	W. Sarafere	M.D.	Drifting	E.	Bright	W.4								8–9
38.*	July 27	N.E. Sarafere	S.		? N.W.										18
39.	July 30 & 31	Between Sarafere & El Oualadji	M.	Copulating on sandbank in early morning					old	100					
40.	Aug. 1	El Oualadji	S.D.		0										
41.	Aug. 7 & 7	Between Koiretago & Korioume	M.		E.			128		20					

APPENDIX I.—*continued.*

Swarm No.	Date	Locality	Type of swarm	Mode of flight	Direction to which swarm was flying	Weather conditions	Wind direction and force	Sex ratio	Age of locusts	% age males yellow	E/F		Sexual dimorphism	Ovarian development	Time
											Male	Female			
42.	Aug. 6	Timbuctoo	L.												
43.*	Aug. 10	Kabara	M.		N.E.										
44.	Aug. 25	Niafunke	L.D.		0										
45.	Sept. 3	Mopti	S.D.		0										
46.	Sept. 6	Tenenkou	L.		W.S.W.										
47.	Sept.	Diafarabe	L.S.	Settled for night	E.			126		23					17 8th
48.	Sept. 25	Between Diafarabe & Macina	S.D.		0										

References.

[1] Chevalier, A. (1900). Actes Ier Congres Int. Bot., Paris, pp. 248–27.
[2] ——. (1933). Bull. Soc. Bot. France, **80,** p. 26.
[3] ——. (1933). Rev. Bot. Appl. et d'Agr. Trop., **13,** pp. 848–892.
[4] Coleno, P. (193–). Bull. Com. Etudes List. Sci. A.O.F., **14,** pp. 218–292.
[5] Cusden, —. (1934). Economic conditions in F. W. Africa. Dept. Overseas Trade, No. 562.
[6] Darnault, P. (1933). Terre, Air, Mer, **49.**
[7] Faure, J. C. (1932). Bull. Ent. Res., **23,** pp. 293–405.
[8] Johnston, H. B. & Maxwell-Darling, R. C. (1931). Bull. Ent. Res., **22,** pp. 399–416.
[9] Lean, O. B. (1931). Bull. Ent. Res., **22,** pp. 365–378.
[10] ——. (1931). Bull. Ent. Res., **22,** pp. 551–572.
[11] Saxton, W. T. (1923). Journ. of Ecology, **12,** pp. 1–38.
[12] Uvarov, B. P. (1928). Locusts and Grasshoppers. Imp. Bur. Ent., London.
[13] ——. (1933). The locust outbreaks in Africa & Western Asia, 1925–31.—Ec. Adv. Coun., Comm. Locust Res.
[14] ——. (1933). The locust outbreaks in Africa & Western Asia, 1932.—*Ibid.*
[15] Zolotarevsky, B. N. (1929). Ann. des Epiphytes, **15,** pp. 185–235.
[16] ——. (1933). Agron. Colon, **185,** pp. 145–148
[17] ——. (1934). Proc. 3rd Int. Locust Conf., pp. 127–134
[18] ——. (1927). 27th Rep. Bur. Sugar Expt. Sta. Queensland.
[19] ——. (1928). A.O.F., Carte d'ensemble politique et administrative.

EXPLANATION OF PLATE III.

Fig. 1. River Niger at Diafarabe at low water including a part of Raunde Island with its *Vetiveria* grassland. May.

,, 2. The same view at high water showing how the *Vetiveria* is inundated. September.

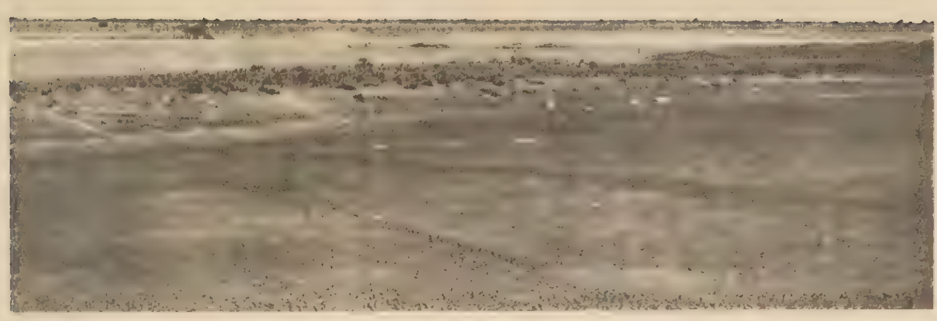

Fig. 1.

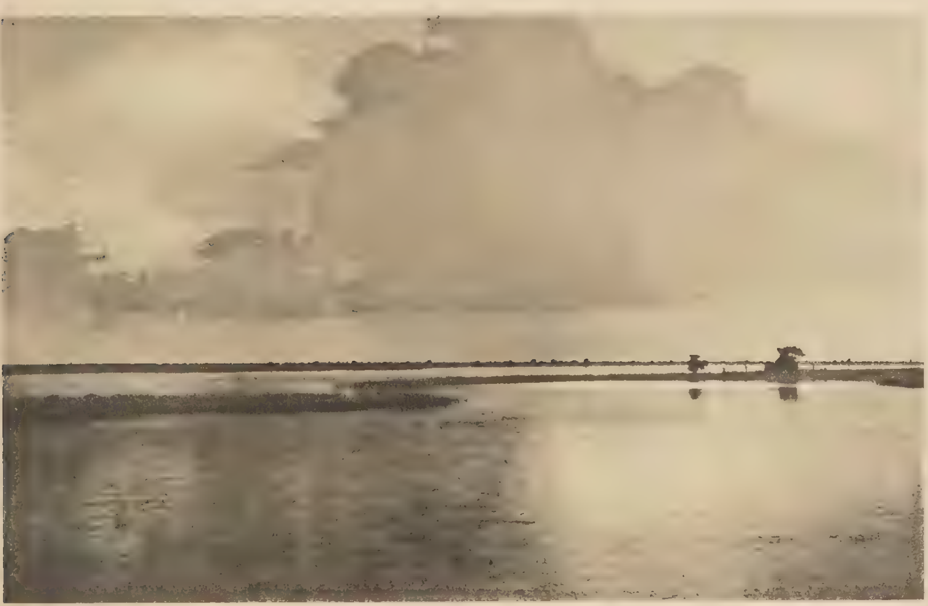

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Fig. 2.

EXPLANATION OF PLATE IV.

Fig. 1. View from Rocher Marie Therese looking south over the great Borghu plain. July.

,, 2. Borghu plain east of Mopti with open water in depression. June.

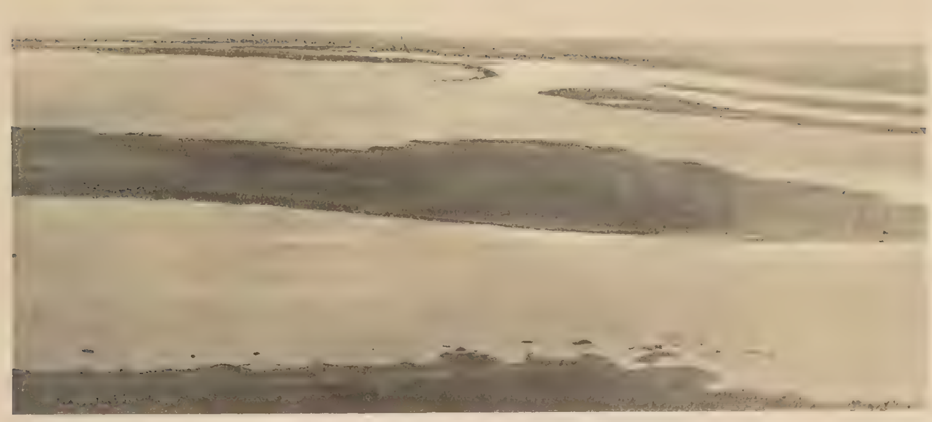

Fig. 1.

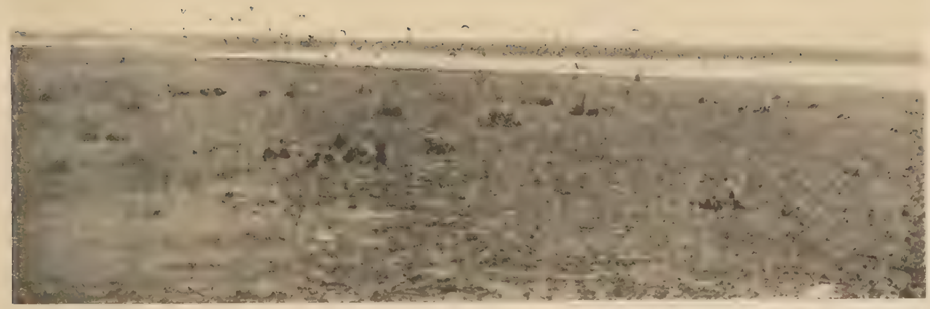

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Fig. 2.

Explanation of Plate V.

Fig. 1. Open *Vetiveria* habitat unscathed by fire along back of Niger Macina. May.

,, 2. Open *Vetiveria* habitat after fire. This is a section of the extensive Dar-es-Salaam plain near Diafarabe where extensive collections of *solitaria* were made. Boys collecting specimens may be seen in the background. May.

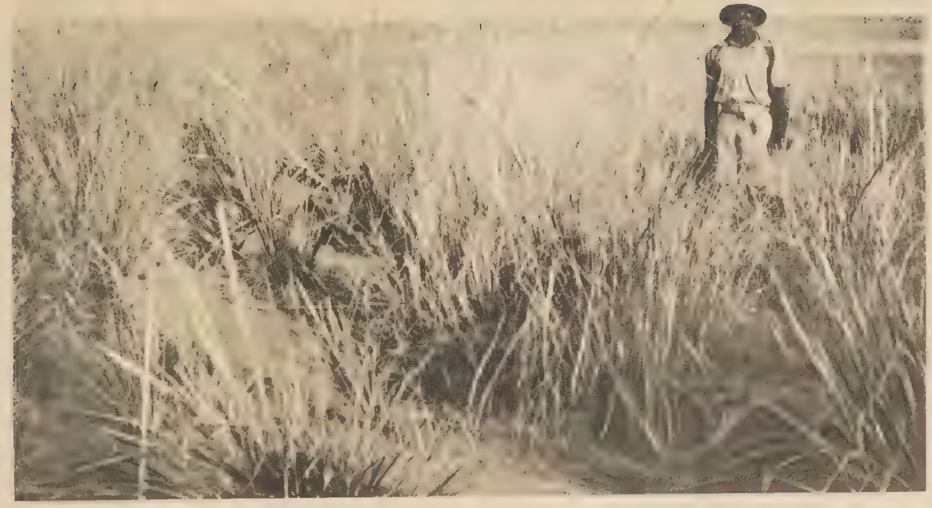

Fig. 1.

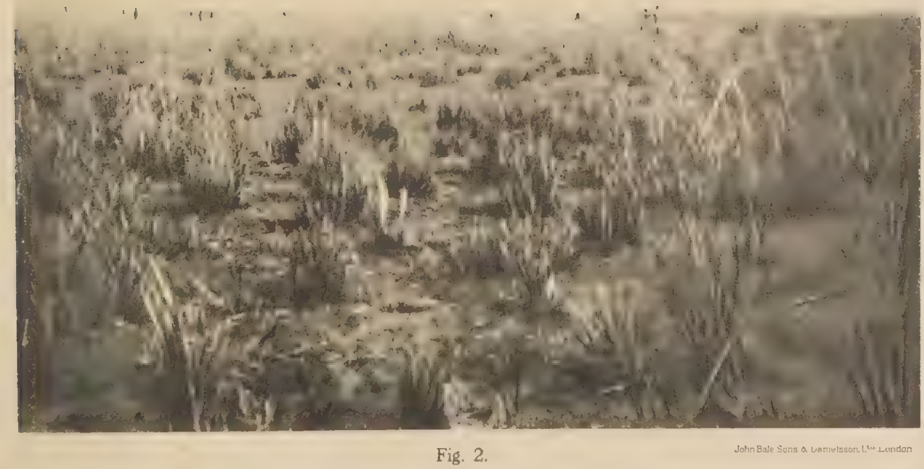

Fig. 2.

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COLLECTIONS RECEIVED.

The following collections were received by the Imperial Institute of Entomology between 1st October and 31st December, 1935.

Mr. A. ALFIERI :—50 Parasitic Hymenoptera ; from Egypt.

ANGLO-EGYPTIAN SUDAN, AGRICULTURAL RESEARCH SERVICE :—4 Coleoptera, 6 Parasitic Hymenoptera, and 6 Lepidoptera ; from the Sudan.

Mr. P. N. KRISHNA AYYAR :—31 Coleoptera and 11 Parasitic Hymenoptera ; from South India.

Mr. E. BALLARD, Government Entomologist :—57 Diptera, 25 Coleoptera, 25 Parasitic Hymenoptera, and 50 cocoons, 48 Lepidoptera, 2,000 Isoptera, 10 Cimicidae, 5 species of Coccidae, 1 species of Aphidae, and 22 other Rhynchota ; from Palestine.

Dr. C. F. C. BEESON, Forest Entomologist :—31 Lepidoptera ; from the United Provinces, India.

Dr. F. S. BODENHEIMER :—15 Coleoptera and 5 larvae, 127 Parasitic Hymenoptera and 25 early stages, 5 Thysanoptera, 34 species of Coccidae, and 3 species of Aphidae ; from Palestine.

Mr. G. E. BODKIN, Director of Agriculture, Mauritius :—6 Diptera, 38 Coleoptera, and 136 Hymenoptera ; from Mauritius and Java.

Dr. G. BONDAR :—95 Coleoptera, 15 Lepidoptera and 4 larvae ; from Brazil.

Mr. P. BORG :—3 Cynipidae and 2 galls ; from Malta.

Mr. H. E. BOX :—81 Curculionidae ; from the British West Indies.

Mr. H. J. BRÉDO :—200 Parasitic Hymenoptera ; from the Belgian Congo.

Dr. A. CHIAROMONTE :—3 Lepidoptera ; from Eritrea.

CHIEF ENTOMOLOGIST, PRETORIA :—70 Coleoptera, 25 Parasitic Hymenoptera, 38 other Hymenoptera, 7 Lepidoptera, 1 species of Aphidae, and 4 Gryllidae ; from South Africa.

Mr. J. T. CHU :—30 Parasitic Hymenoptera and 20 cocoons ; from China.

Mr. A. F. CLARK :—1 Cerambycid ; from New Zealand.

Dr. E. A. COCKAYNE :—133 Parasitic Hymenoptera and 150 cocoons ; from Great Britain and Germany.

COCONUT EXPERIMENT STATION, CELEBES :—100 Parasitic Hymenoptera ; from the Dutch East Indies.

Father P. A. CONRADS :—434 Coleoptera ; from Tanganyika Territory.

Mr. G. H. CORBETT, Government Entomologist :—140 Diptera and 15 pupa cases, 228 Coleoptera, 149 Parasitic Hymenoptera, 66 other Hymenoptera, 113 Lepidoptera, 500 Isoptera, 90 Rhynchota, 3 Psocidae, 13 Orthoptera, 16 Dermaptera, 4 Ephemeridae, and 6 Shells ; from Malaya.

CORYNDON MEMORIAL MUSEUM, NAIROBI :—27 Tabanidae, 3 *Stomoxys*, 281 other Diptera, 185 Hymenoptera, 2 Rhynchota, and 2 Chelifera ; from East Africa.

Mr. A. CRÈVECOEUR :—10 Parasitic Hymenoptera ; from Belgium.

Mr. R. C. M. DARLING :—2 Hymenoptera, 12 Lepidoptera, and 226 Orthoptera ; from Aden.

Dr. J. DESHUSSES :—50 Parasitic Hymenoptera ; from Switzerland.

Miss Z. DICKSON :—11 Orthoptera ; from Arabia.

Director of Agriculture, Sandakan :—101 Orthoptera ; from North Borneo.

Director of Public Works, Lagos :—410 Isoptera ; from Nigeria.

Mr. V. H. W. Dowson :—16 Lepidoptera and 30 Rhynchota ; from Iraq.

European Parasite Laboratory, Hyères :—50 Parasitic Hymenoptera and 10 cocoons, and 5 Rhynchota ; from France.

Mr. J. L. Froggatt, Government Entomologist :—4 Diptera, 25 Coleoptera, 4 Parasitic Hymenoptera, 4 other Hymenoptera, 4 Lepidoptera, and 8 Rhynchota ; from New Guinea.

Dr. L. Fulmek :—1,300 Parasitic Hymenoptera and 100 cocoons ; from Austria

Mr. S. Garthside :—6 Coleoptera, 21 Parasitic Hymenoptera and 18 cocoons ; from England.

Mr. J. Ghesquière :—163 Coleoptera ; from the Belgian Congo.

Mr. F. D. Golding, Government Entomologist :—22 Diptera, 63 Coleoptera, 4 Parasitic Hymenoptera, 46 Lepidoptera, 7 species of Aleurodidae, 45 other Rhynchota, and 14 Orthoptera ; from Nigeria.

Government Entomologist, Coimbatore :—60 Diptera, 24 Coleoptera, 10 Parasitic Hymenoptera, 10 other Hymenoptera, 52 Lepidoptera, 1 species of Aphidae, 8 other Rhynchota, and 2 Dermaptera ; from South India.

Government Entomologist, Kampala :—200 Parasitic Hymenoptera and 10 cocoons, and 77 Lepidoptera ; from Uganda.

Government Entomologist, Lyallpur :—12 Diptera and 2 pupa cases, 6 Coleoptera, 12 Parasitic Hymenoptera, and 5 Rhynchota ; from the Punjab.

Mr. H. Gumbleton :—35 Parasitic Hymenoptera ; from England.

Mr. K. Günther :—6 Curculionidae ; from Costa Rica.

Mr. E. Hargreaves, Government Entomologist :—2 *Glossina*, 57 other Diptera, and 30 early stages, 331 Coleoptera, 364 Parasitic Hymenoptera, 69 other Hymenoptera, 183 Lepidoptera, 220 Thysanoptera, 102 Rhynchota, 21 Orthoptera, 4 Planipennia and 300 early stages, 3 Odonata, and 23 Trichoptera ; from Sierra Leone.

Mr. W. V. Harris, Assistant Entomologist :—7 Diptera and 5 Coleoptera ; from Tanganyika Territory.

Mr. K. J. Hayward :—1 Tortricid ; from Argentina.

Mr. E. P. Hodgkin :—8 Tabanidae, 27 *Stomoxys*, and 114 other Diptera ; from Malaya.

Dr. W. Horn :—14 Coleoptera ; from South America.

Dr. A. D. Imms :—150 Parasitic Hymenoptera ; from England.

Imperial Entomologist, Pusa :—89 Diptera, 79 Coleoptera, 120 Parasitic Hymenoptera, 3 other Hymenoptera, 15 Lepidoptera, 25 Isoptera, 19 species of Aphidae, 1 species of Psyllidae, 31 other Rhynchota, 3 Planipennia, and 3 Mites ; from India.

Institute for Plant Diseases, Buitenzorg :—146 Coleoptera, 45 Lepidoptera, and 3 species of Coccidae ; from the Dutch East Indies.

Indian Lac Research Institute :—50 Diptera and 35 Parasitic Hymenoptera ; from Bihar, India.

Mr. J. M. Kelsey :—20 Parasitic Hymenoptera ; from New Zealand.

Mr. T. W. Kirkpatrick :—2 Parasitic Hymenoptera, 10 Stylopidae and 50 Stylopised Rhynchota, and 7 other Rhynchota ; from Tanganyika Territory.

Mr. H. Kutter :—200 Parasitic Hymenoptera ; from Switzerland.

Dr. W. A. Lamborn, Medical Entomologist :—36 Culicidae and 56 *Glossina* ; from Nyasaland and Bechuanaland.

Mr. R. A. Lever, Government Entomologist :—9 Culicidae, 5 Tabanidae, 48 other Diptera, 103 Coleoptera and 6 larvae, 30 Hymenoptera, 6 Rhynchota, 6 Orthoptera, 20 Ephemeridae, 20 Mallophaga, and 10 Parasitic Worms ; from the Solomon Islands.

Dr. E. A. Lewis, Veterinary Entomologist :—1 Bombyliid and 2 Coleopterous larvae ; from Kenya Colony.

Mrs. K. C. Mackay :—1 Anobiid, 1 Ichneumonid, and 1 Cercopid ; from Ireland.

Mr. A. Manjikul :—46 Coleoptera, 40 Parasitic Hymenoptera, 373 Lepidoptera, 20 Rhynchota, and 3 Orthoptera ; from Siam.

Mr. M. C. Mossop, Assistant Entomologist :—16 Coleoptera, 10 Lepidoptera, 7 species of Aleurodidae, 4 other Rhynchota, and 100 Mites ; from Southern Rhodesia.

Mr. J. Muggeridge, Government Entomologist :—1 species of Eriophyidae and 1 species of Eelworm ; from New Zealand.

Mr. R. W. Mungomery :—52 Diptera, 6 Parasitic Hymenoptera, and 29 Rhynchota ; from Queensland.

Musée du Congo Belge :—4 Coleoptera ; from Belgium.

Sir Francis A. Newdegate :—1 species of Mite ; from England.

Mr. R. W. Paine :—2 Diptera, 7 Coleoptera, 7 Parasitic Hymenoptera, and 2 Rhynchota ; from the Fiji Islands.

Mr. J. Palmoni :—300 Collembola ; from Palestine.

Mr. F. S. Parsons :—9 Parasitic Hymenoptera ; from South Africa.

Mr. E. F. Peck, Veterinary and Agricultural Officer :—4 Coleoptera, and 2 larvae, 26 Hymenoptera, 5 Lepidopterous larvae, 19 Isoptera, 93 Rhynchota and 150 early stages, and 832 Orthoptera ; from British Somaliland.

Messrs. Peek, Frean & Co., Ltd. :—10 Coleoptera and 200 larvae, and 100 Lepidoptera ; from England.

Messrs. Pullman Car Co., Ltd. :—3 Coleoptera ; from England.

Mr. S. Ananda Rau :—3 Diptera, 30 Coleoptera, 8 Parasitic Hymenoptera, 6 Lepidoptera, 14 Isoptera, and 1 species of Aphidae ; from South India.

Mr. P. Regnier :—2 Coleoptera, 66 Parasitic Hymenoptera, 21 Isoptera, 3 Planipennia, and 2 Odonata ; from Morocco.

Mr. P. B. Richards :—3 Diptera, 34 Parasitic Hymenoptera and 4 cocoons, and 4 Lepidoptera ; from India.

Mr. A. H. Ritchie, Government Entomologist :—55 Parasitic Hymenoptera and 11 Lepidoptera ; from Tanganyika Territory.

Mr. René-Paul Robá :—30 Parasitic Hymenoptera and 1 species of Coccidae ; from Colombia.

Messrs. Robinson, Ltd. :—6 Coleoptera ; from England.

Mr. G. Roland :—1 Capsid ; from Belgium.

Dr. G. Russo :—89 Parasitic Hymenoptera ; from Italy.

Mr. R. N. Savory :—18 Tachinidae and 25 pupa-cases, and 3 Lepidoptera ; from Surinam.

Mr. Nihat Schewket :—3 species of Aphidae ; from Asiatic Turkey.

Selangor Museum :—252 Coleoptera ; from Malaya.

Mr. C. Smee, Government Entomologist :—36 Diptera and 31 pupa-cases, 9 Coleoptera, 9 Parasitic Hymenoptera, and 2 Rhynchota ; from Nyasaland.

Mr. A. C. W. Wagner :—4 Parasitic Hymenoptera ; from Germany.

Mr. H. V. Weiss-Wichert :—10 Parasitic Hymenoptera ; from Germany.

Mr. F. G. S. Whitfield :—63 Culicidae ; from the Sudan.

Mr. H. Wilkinson, Entomologist :—1 species of Aphidae ; from Kenya Colony.

Mr. F. X. Williams :—141 Diptera and 40 early stages ; from Hawaii.

Mr. A. R. Woodhill :—16 Curculionidae ; from New South Wales.

Dr. F. Zacher :—43 Lepidoptera ; from Germany.

THE PHYSICAL ECOLOGY OF *MICROPLECTRON FUSCIPENNIS*, ZETT. (HYM. CHALC.).

By G. C. Ullyett, B.Sc., Dip.Agric.,

Farnham House Laboratory, Imperial Institute of Entomology.

Introduction.

Microplectron fuscipennis, Zett., is an important parasite of the Pine Sawfly, *Diprion sertifer*, Geoff., in Europe. It is distributed widely over the Continent from Scandinavia down to the Adriatic coastline. It has recently been the subject of investigations in the field by Dr. K. R. S. Morris and Mr. E. Cameron, of this Laboratory, on behalf of the Canadian Government. The records of their survey are embodied in a paper on the biology of the species (Morris & Cameron, 1935). As a result of their work the parasite was shipped in numbers to Canada for use against *Diprion polytomum*, Htg., a European species allied to *D. sertifer*, which was accidentally introduced into that country some time ago, and is now a serious pest of spruce in the Gaspé Peninsula.

Beyond these field observations, nothing is known of the reactions of the parasite to climatic factors, although the records obtained indicate that there are very definite optimum localities having special environmental conditions of temperature and humidity. At the suggestion of Dr. W. R. Thompson, the author undertook a study of the physical ecology of the parasite as part of a larger programme of work embracing the general ecology of *Microplectron*, which will be completed as time permits. The present paper records the facts obtained in this preliminary investigation.

I have to thank Dr. Thompson not only for suggesting this subject and for laboratory facilities for carrying out the work involved, but also for his kindly interest and encouragement throughout. To Dr. K. R. S. Morris and Mr. E. Cameron I am indebted for much information relating to *Microplectron* in the field.

I. The Influence of Humidity.

While it has been realised for some considerable time that a zone of optimum atmospheric humidity exists for any one insect, wherein, under favourable conditions of temperature, functional activities are at their maximum, it is only within recent years that the subject has been investigated scientifically. Up to the present, however, the work accomplished has been concerned mainly with insects of medical and public health importance. The significance of humidity in relation to phytophagous insects has been stressed comparatively recently by the work of a number of investigators, among which may be mentioned the observations of Lean (1931) on the swarming of *Locusta migratoria migratorioides*, Rch. & Frm., in tropical Africa, of Roubaud (1933) on *Schistocerca gregaria*, Forsk., and the laboratory work of MacGill (1931) on the immature stages of *Thrips tabaci*, Lind. With a few exceptions, the vast field afforded by entomophagous insects has been practically unexplored.

The importance of atmospheric humidity lies in its relation to the evaporation of moisture from the body of an insect. Buxton (1932), working with fasting larvae of the Meal-worm, *Tenebrio molitor*, L., found that the evaporation from this insect was proportional to the saturation deficiency of the atmosphere to which it was exposed. This was supported by the work of Mellanby (1932) on bed-bugs. These results indicate that the correct measure of humidity in investigations on insects is that of saturation deficiency, rather than relative humidity, which has been the usual method in the past. On the other hand, Maercks (1933), dealing with the mortality of eggs of *Microbracon hebetor*, Say, obtained diametrically opposite results and found a positive correlation with relative humidity and not with saturation deficiency. His findings were confirmed by the observations of Janisch and Abdel Aziz Elsayed Ghabn (1933) on the young larvae of *Bombyx mori*, L. Similarly, Leeson (1932) found that there was no direct proportion between the survival of unfed rat fleas and the saturation deficiency of the atmosphere at any temperature.

It is known that small insects dry up more rapidly than do larger ones on account of their proportionately greater ratio of surface area to volume. A small insect is, therefore, at a serious disadvantage when brought into contact with a dry atmosphere. Certain insects, however, are able to control the rate of evaporation from the body to a certain extent, or to make good the loss of moisture from this cause by an adjustment of their metabolism (Buxton, 1932). Others, again, migrate to areas of more favourable humidity where this is possible. The physical reactions and adaptations of insects to varying degrees of humidity are admirably summarized by Kennedy (1927).

It seems, therefore, that insects differ widely in their humidity relationships and that the influence of the moisture content of the atmosphere upon the various phases of life cannot be stated with certainty for any one insect, except upon definite experimental evidence. It is too early, as yet, to formulate any important generalisations which would be applicable to insect life as a whole.

(*a*) **Technique.**

For the purpose of the present investigations, the position as found by Buxton and Mellanby, quoted above, was accepted provisionally and in comparing the effect of different conditions of humidity on the various stages in the life cycle of *Microplectron*, the atmosphere to which exposure was made was in each case conditioned to give a known saturation deficiency.

It was found convenient to keep the adult parasites used in the experiments in glass tubes (3 by 1 in.), which were divided a little below the centre by a tightly-fitting ring of cork, over which muslin was fastened. This admitted of free continuity of air throughout the tube. Below the ring was a small quantity of a mixture of sulphuric acid and water giving the required saturation deficiency to the atmosphere above. The parasites were confined in the upper portion of the tube, above the dividing ring, being collected directly therein by means of a suction tube. The whole tube was kept tightly corked and was placed under the desired conditions of temperature. Food for the parasites was provided in the form of a single raisin fastened to the cork of the tube, a fresh one being supplied daily.

While the presence of the raisin undoubtedly affected the humidity of the air immediately surrounding it, the effect on the atmosphere of the tube as a whole was slight. Moreover, it is more prolonged, and therefore more marked, in the higher range of humidity than in the lower, for the simple reason that the moisture from the raisin is absorbed more rapidly under the latter conditions. The importance of providing a source of food more than outweighed any disadvantage accruing therefrom. It was demonstrated in a preliminary trial, in which starved adults showed a 20 per cent. higher mortality over a short period of time (3 days) than did those which received food. This is of particular importance in oviposition studies, while in the longevity experiments, the mortality due to starvation tends to obscure any humidity effects.

The simple apparatus described above proved to be eminently satisfactory and was convenient both in handling and in the maintenance of cleanliness. The accompanying chart (fig. 1) proved useful in preparing the mixtures of acid and water, the required saturation deficiencies being first translated into terms of relative humidity with the aid of the curves published by Buxton (1931).

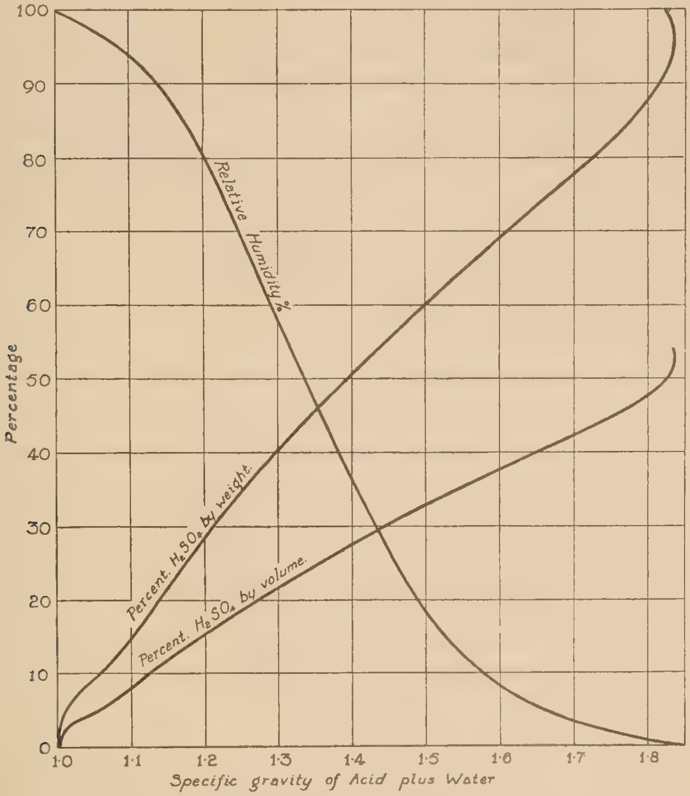


Fig. 1. Curves showing the relation between the relative humidity of the atmosphere, the specific gravity of mixture of sulphuric acid and water, and the percentage concentration of acid by weight and volume.

The available records of the natural parasitism of Pine Sawflies by *Microplectron* in Europe show that the maximum efficiency of the parasite, found under field conditions, is attained where the mean summer temperature is in the neighbourhood of 20°C. In the following experiments the different series were maintained at a constant temperature of 20°C., this being accepted, arbitrarily, as the optimum temperature. That this is not necessarily the case is discussed under the section dealing with temperature effects. In most cases confirmation of the results obtained at this temperature was forthcoming from parallel series kept at higher temperatures.

(*b*) **Influence on Longevity.**

In the following series, observations were limited to female parasites. Males were included in every case but were considerably shorter-lived than the females, and only mating activities were noted. Freshly emerged females were confined in tubes as described above, 40 being placed in each tube. A total of 160 females was used in each series. They were exposed to a constant temperature of 20°C. (68°F.) for 10 days. The humidity of the atmosphere in the tubes ranged from very dry (a saturation deficiency of 17 mm. mercury) to saturation. At the end of 10 days the number remaining alive in each humidity was counted and the percentage survival ascertained.

The results thus obtained are shown graphically (fig. 2), which indicates clearly that a very dry atmosphere is inimical to the parasites. Premature mortality under these conditions is the result of a too rapid evaporation from the body of the insect, terminating in desiccation. This effect first becomes noticeable at a saturation deficit of 5 mm., and increases rapidly in intensity until the limit of 17 mm. is reached. At this latter point the majority of females were dead after 3 days' exposure, and all were dead by the sixth day. The same was true for the 14 mm. series. The significance of this is more readily appreciated when it is stated that the normal average length of life under laboratory conditions is approximately 14 days, and that under favourable conditions a good proportion of females will exceed this by two or three days. In the other direction there is a gradual improvement in conditions from 4 mm. down to saturation, with the optimum at the latter point. Confirmation of these results was obtained at both 25° and 30°C.

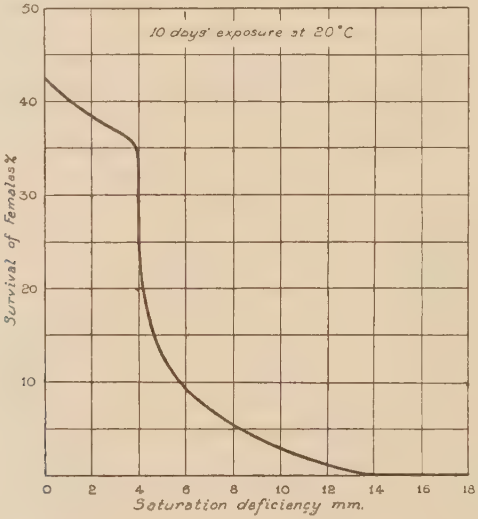


Fig. 2. *Microplectron fuscipennis*: Survival of females at a constant temperature of 20°C. and at various saturation deficiencies.

(*c*) **Influence on Oviposition.**

Six freshly emerged females were confined in each tube together with two or three males and six cocoons of the host (*Diprion sertifer*, Geoff.), containing resting-stage larvae. The cocoons were fastened to a section of card suitably cut to fit the upper portion of the tube. The tubes were exposed to a constant temperature of 20°C. in a glass-fronted incubator, so that oviposition could proceed in daylight. It had been found previously that artificial light was unsuitable, giving a marked irregularity of results. This was mainly due to the difficulty of obtaining an equal distribution of light over all the containers, and hence a sufficient intensity of light in each individual case.

With the great majority of females it was found that the stinging of the host larva and subsequent oviposition in the cocoon occupied more than 24 hours. Hence, to change the cocoons daily not only resulted in a waste of host material (an appreciable number having no eggs deposited on them), but seriously interrupted the female in her operations, with a consequent reduction in daily egg-production. In all cases, therefore, cocoons were removed every alternate day, each female receiving one cocoon at this interval until death supervened. On removal the cocoons were opened and the contained parasite eggs were counted.

The results are shown in the accompanying curve (fig. 3), the data having been obtained from 50 females in each humidity series. It is obvious that a high humidity is again an important factor in producing maximum efficiency. A dry atmosphere reduces the oviposition to a minimum. On the other hand, a wide range of tolerance is exhibited, extending from a saturation deficiency of 10 mm. down to saturation. Within this range the female is able to deposit the great majority of her eggs before death. If a comparison is made between figures 2 and 3, it will be seen that the curve for oviposition does not follow an identical course with that for longevity, although still sigmoid in shape. A much wider tolerance characterises the former ; while, except where death occurs very early, the total production of eggs is by no means proportional to the length of life. This aspect is discussed further in a later section of the paper.

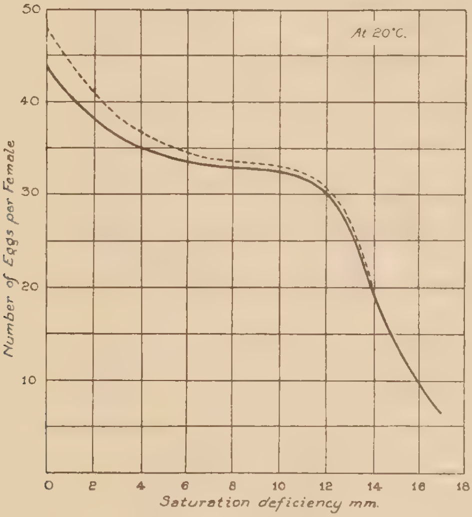


Fig. 3. *M. fuscipennis* : Oviposition at a constant temperature of 20°C. and at different saturation deficiencies.

A further interesting fact also emerged from the experiment. At a saturation deficiency of 14 mm. and 17 mm., the females were very frequently unable to paralyse the host larva, as is normal prior to oviposition, although penetration of the cocoon was accomplished successfully and eggs were deposited on the healthy, living larva within. Occasionally the same thing occurred at 10 mm. but never at higher humidities. This is clearly a direct result of the high evaporating power of the air which, through causing excessive loss of moisture from the body, presumably deprives the poison glands of an adequate supply.

(*d*) **Influence on the Developmental Period.**

The eggs of *Microplectron* are deposited on the larva lying within the cocoon of the sawfly. Any attempt to ascertain the effect of humidity on the incubation period of the egg alone would involve the opening of the cocoon. This operation would disturb the micro-climate to which the egg is normally exposed ; the significance of which, in its relation to the humidity of the macro-climate, is discussed below. For this reason it was impossible to make separate observations on the incubation period with any degree of accuracy, and the present experiments were based on the combined egg and larval development periods. In other circumstances this might be regarded as a serious omission, since the problem presented by an insect egg may well be distinct from that of the adult or larva. From the nature of the situation obtaining in the present instance, however, it is safe to assume that the conditions most favourable for larval development are *ipso facto* the optimum conditions for the growth of the embryo and the hatching of the egg.

For parasitism, host cocoons were exposed to an adequate number of mated females for 36 hours, after which they were removed and placed singly in small glass tubes, the mouths of which were plugged loosely with cotton-wool. They were then placed over appropriate mixtures of acid and water in desiccating jars, which were kept at a constant temperature of 20°C. As before, the range of humidity was from very dry to saturation. Fifty cocoons were used in each series. After emergence had definitely ceased, the remaining cocoons were opened, the unparasitised ones were deducted and the remainder analysed to show in what stage of development the death of the parasite had taken place. The results of this analysis, together with other data, are shown in Table I.

TABLE I.

The Effect of Humidity on the Development and Developmental Period (Egg-Adult) of Microplectron fuscipennis.

Saturation deficiency : mm. mercury	Initial no. of cocoons	No. of cocoons parasitised	No. of cocoons giving emergents	Percentage of parasitised cocoons	Analysis of remainder*			Period in days		
					A	B	C	Max.	Min.	Mean.
0	50	32	29	90·6	—	3	—	23	16	18·9
2	50	32	28	87·5	—	4	—	22	17	19·3
3	43	25	21	84·0	—	4	—	25	19	21·8
3·5	43	23	19	82·7	—	3	1	22	19	20·1
4	43	29	27	93·1	—	2	—	22	19	20·4
5	50	44	33	75·0	7	3	1	26	20	21·5
7	50	35	30	85·7	—	4	1	23	17	19·3
10	50	44	33	75·0	8	3	—	25	20	20·3
14	50	47	33	71·3	9	4	1	27	20	21·1
17	50	40	9	22·5	26	4	1	23	20	21·4

* A : Parasites died early in development (egg or young larva) ; B : Parasites died as adults before emergence from the cocoon ; C : Parasites died as pupae.

It is apparent at once that the humidity of the atmosphere has no effect upon the length of the developmental period. In all cases the parasite took approximately the same length of time from oviposition to emergence. This agrees with the recent record of Buxton & Lewis (1934) on puparia of *Glossina tachinoides*. The one striking result is the extraordinarily wide range of tolerance displayed to different conditions of atmospheric humidity, as shown by the figures for the percentage of the parasitised cocoons which gave emergents (column 5). With the sole exception of the very dry air (saturation deficiency of 17 mm.), this percentage was consistently high. A study of the analysis of those cocoons which failed to yield parasites, however, shows that the actual adverse effect of low humidity really became apparent in the 10 mm. series. This was reflected in the number of cases in which the parasites died either before hatching from the egg or as young larvae. Nevertheless, it became seriously detrimental to the reproduction of the parasite only in the very dry air, in which the majority of eggs present did not hatch but became desiccated. The number of cases in which the parasite died after attaining maturity, but before emergence from the cocoon could occur, was fairly constant throughout and may therefore be disregarded in the present discussion. There was no apparent reason for the presence of this feature.

The remarkable tolerance evinced by the developing parasites can only be explained reasonably in one way. The presence of a surrounding, closely-woven envelope (the cocoon) introduces a situation which gives the fullest scope to the development and maintenance of a very specialised micro-climate—one in which the conditions of humidity are regulated by the evaporation from the body of the host larva and are protected, within wide limits, from the influence exerted by the outside air. In other words, so far as humidity is concerned, the host is able to create and maintain a climate essentially its own within the cocoon. Only in the extreme case of practically totally dry air does this break down entirely. This view can only be true if the material of which the cocoon is constructed possesses a marked power of controlling evaporation of moisture from within and of preventing the inward diffusion of moisture from the macro-climate. The subject seemed to be worth further investigation.

(*e*) **The Function of the Cocoon in Relation to Humidity.**

The literature dealing with this subject is meagre and deficient in experimental evidence. The only paper of importance containing reference to it appears to be that of Urech (1890), in which observations are recorded on the protective value of the cocoons of *Malacosoma neustria*, L., against desiccation of the pupae. Urech found that a pupa that was removed from its cocoon lost up to 9·42 per cent. of its weight during a period of five days, whereas the presence of the cocoon reduced this loss to only 3·5 per cent.

At present there is no known method of measuring accurately the humidity of the micro-climate in such small and entirely enclosed situations as the interior of a cocoon. The difficulty seems insurmountable, in that the introduction of any instrument for this purpose would involve the rupture of the envelope, with a consequent and immediate disturbance of the internal atmosphere by the establishment of continuity with the macro-climate. Any attempt to assess the value of the cocoon in relation to the stabilisation and protection of the micro-climate must therefore be by deductive methods. The following experiments were carried out with healthy, unparasitised cocoons containing resting stage larvae of *Diprion sertifer.*

In the first experiment five lots of 25 cocoons were weighed and were exposed in desiccators, at a constant temperature, to saturated atmosphere and to each of four different atmospheres conditioned to give saturation deficits of 3·5 mm., 7 mm., 14 mm., and 17 mm. respectively. After a period of 7 days the cocoons were removed and again weighed. The loss in weight for each series is shown in the curve (fig. 4) which actually represents loss of moisture by evaporation. It will be noticed that the loss in weight was proportional to the saturation deficiency of the atmosphere to which they had been exposed, but that the total loss, except at the lowest humidity (17 mm.), was small. There was a gain in weight of approximately 2 per cent. under conditions of saturation, as is shown in the curve. This might have been due to the absorption of moisture by the material of the cocoon, to absorption by the contained larva, or to both causes in conjunction. Similarly, in the cases where loss of moisture occurred, it is not clear from the above what proportion of the loss is experienced by the cocoon and what proportion by the larva.

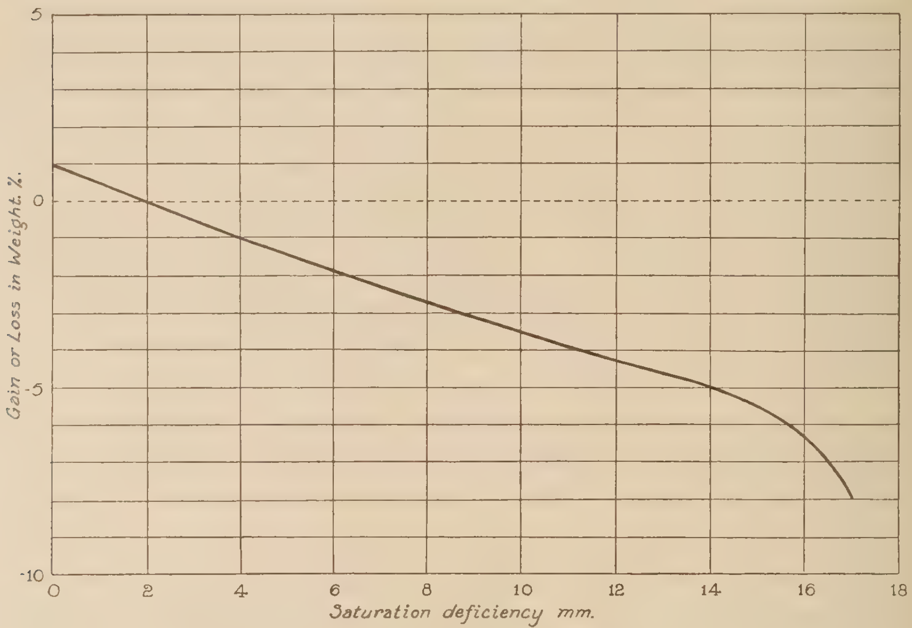


Fig. 4. Evaporation from cocoons of *Diprion sertifer* : Curve showing gain or loss in weight after seven days' exposure to different humidities.

The next step was to ascertain the loss or gain of moisture sustained by the cocoon itself. The larvae were removed and the empty cocoons were exposed to a saturated atmosphere and to atmospheres showing saturation deficiencies of 7 mm., 14 mm., and 17 mm. respectively. There were 20 cocoons in each series and the whole experiment was maintained at a constant temperature until no further change in weight occurred. The results obtained are shown in Table II.

TABLE II.

Diprion sertifer : *Absorption or Loss of Water by the Cocoon alone.*

Saturation deficiency : mm. Hg.	Weight in grams at successive weighings				Percentage loss or gain in weight			
	1	2	3	4	1	2	3	4
0	0·1890	0·2192	0·2192	0·2192	—	+15·9	—	—
7	0·1987	0·2061	0·2061	0·2061	—	+3·7	—	—
14	0·1940	0·1932	0·1932	0·1932	—	−0·4	—	—
17	0·1881	0·1790	0·1656	0·1656	—	−4·8	−11·9	—

In a saturated atmosphere the cocoon absorbs moisture to the extent of 15·9 per cent. of its initial weight. But the weight of the material of the cocoon was found to be only 13 per cent. of the total weight of the cocoon plus its contained larva, which represents normality and, for convenience of reference, will be referred to henceforth as the "normal host." This gain in weight, expressed as a percentage of the total weight of the normal host, is reduced therefore to 2 per cent., which accords with the findings in the first experiment, where a similar gain was registered under identical conditions. Hence the gain in weight of the host in that case was due entirely to absorption of moisture by the cocoon alone. The process ceases after the first three days. From these results it may be inferred that the moisture taken up by the cocoon is not passed on to the micro-climate or absorbed by the enclosed larva ; or, alternatively, that the micro-climate must be very near saturation and hence is incapable of receiving moisture from the cocoon in any noticeable quantity. In view of the fact that the cocoon allows a slow outward diffusion of moisture under dry conditions, it seems that the reverse must hold good, in which case the last-named alternative can be accepted as true. The position encountered in dry air can be discussed to better advantage when the reactions of the larva itself have been examined.

Twenty naked larvae were weighed and exposed to dry air at a saturation deficiency of 17 mm., and to a constant temperature of 20°C. Regular daily weighings were made. The larvae lost weight rapidly, until by the seventh day they had lost 28·2 per cent. of their initial weight. Death due to desiccation occurred at this point. As the larva provides 87 per cent. of the total weight of the normal host, evaporation had accounted for 24·6 per cent. of the total weight of the latter (fig. 5).

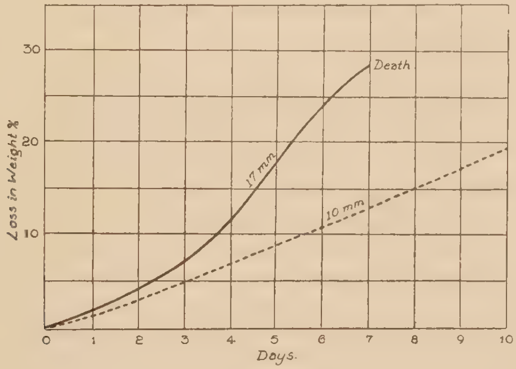


Fig. 5. Evaporation from naked larvae of *Diprion sertifer* at 20°C. and at different saturation deficiencies.

Referring back to Table II, it will be seen that the empty cocoon, under identical conditions, lost 11·9 per cent. of its initial weight within 7 days. This is equivalent to 1·6 per cent. of the total weight of the normal host. The latter, however, has been shown (fig. 4) to lose 7·08 per cent. of its weight during the same period of exposure. Hence the larva, of itself, has lost by evaporation 5·48 per cent. of the total weight. Now a naked larva, after the same exposure to air of the same saturation deficiency, loses 24·6 per cent. of the total weight, which proves fatal. The cocoon, therefore, is directly responsible for a conservation of moisture amounting to approximately 19 per cent. out of a total possible loss of 24·5 per cent. ; a saving of about 77·6 per cent. Moreover, the survival of the host in its present stage under conditions of adverse (low) humidity is determined very obviously by the presence of the cocoon. The relationship between the rates of evaporation in the three cases considered here is shown graphically (fig. 6), the loss in weight being represented as a percentage of the total weight of the normal host.

The cocoon of *Diprion sertifer* clearly exercises a controlling influence on the interchange of moisture between the micro-climate and the external atmosphere. This only fails in its purpose in extremely dry air ; a condition which is very unlikely to be encountered in its normal environment. Hence the contained larva is able to maintain the humidity of the micro-climate in that state of equilibrium which is most suitable for its own development, and which also constitutes optimum conditions for parasite development.

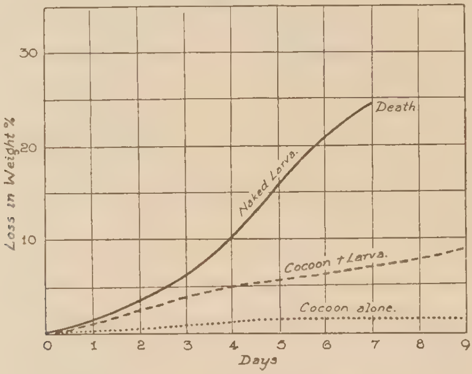


Fig. 6. Evaporation from the host (*D. sertifer*), expressed as percentage loss in weight, in dry air and at 20°C.

(*f*) **Summary of the Influence of Humidity.**

The experiments recorded above show that in every phase of its functional activity *Microplectron* requires an atmosphere of low saturation deficiency in order to attain to maximum efficiency. In the important period of egg and larval development the parasite is at the disadvantage of being confined to one definite site for a considerable length of time, irrespective of any atmospheric changes in that environment. The micro-climate is fortunately under a control sufficiently competent to maintain suitable conditions of humidity which are, to a great extent, independent of change in the macro-climate. It is rarely, if ever, that the host will be exposed normally to such a high saturation deficiency that this control will break down entirely.

The adult presents a different problem, in that its power of movement enables it to seek out situations which are more favourable to life (*vide* the observations of Darby, 1933, on the Braconid *Diachasma crawfordi*, Vier.). The correlation exhibited between longevity, oviposition and atmospheric humidity, however, leads to the conclusion that the parasite will prove to be most successful in a moist climate, other conditions being equal. The relation of the laboratory findings to the available field observations will be discussed later.

II. The Influence of Temperature.

The literature dealing with the effect of temperature upon insect life is considerably more extensive than that relating to the influence of humidity, especially in the case of entomophagous insects. This is undoubtedly due to the fact that in the field the effects of temperature are always more obvious than those of humidity, and hence the latter are masked by the former. The extent of our knowledge of the reactions of insects to temperature is revealed in the able summary by Uvarov

(1931). From this it is clear that in the present instance the position is more generalised than with humidity. We can state with some degree of confidence what will be the general effect of rising temperatures upon the activities, both functional and general, of any insect; although for detailed knowledge upon such questions as, for example, the actual extent of oviposition, we have to resort to definite experimental evidence.

In any bioclimatic study, temperature cannot be divorced from humidity. A suitable environmental humidity is a necessary basis upon which to found temperature experiments. Temperature, of itself, becomes a limiting factor when too high or too low, and it is important to know not only the thermal death points but also the upper and lower limits for the activity of the insect when the atmospheric humidity is constant and favourable. Between these two limits a rising temperature accelerates development, activity and life processes in general. These effects must be ascertained for each individual species. As has been pointed out by various other writers, not only does this effect vary with different insects but also with the various stages in the life-cycle of the same insect.

(*a*) **Technique.**

The apparatus used was the same as that for the humidity experiments. Each constant temperature series was maintained at the same constant condition of saturation deficiency, based upon the optimum conditions as determined previously. The adult parasites were fed as before and, in the case of the oviposition studies, were kept in daylight in a glass-fronted incubator. Freshly emerged adults from a common stock, of approximately uniform size and reared under identical temperature conditions, were used in every case. The developmental periods were determined as in the humidity trials, but at a constant atmospheric humidity.

(*b*) **Influence on Longevity.**

One hundred and sixty females were confined in tubes at each temperature at a constant saturation deficiency of 3 mm. mercury. They were exposed for a period of 10 days, after which the percentage survival was ascertained. The results are shown in the accompanying curve (fig. 7). This exhibits the usual acceleration of

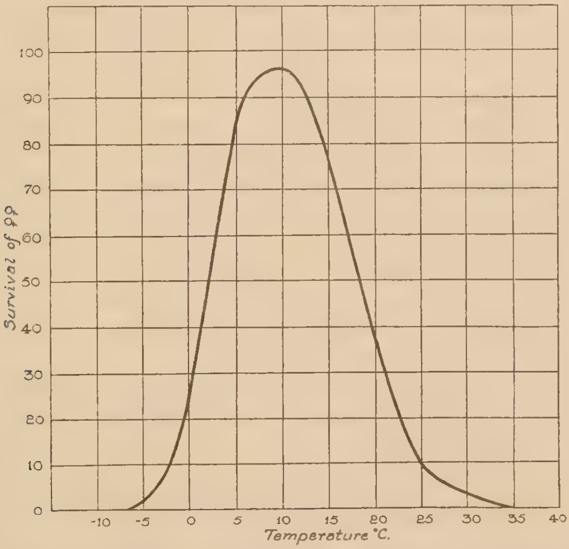


Fig. 7. *Microplectron fuscipennis*: Effect of temperature on the longevity of females; curve for survival after 10 days' exposure.

physiological senility associated with increased temperature, together with a similar but reversed effect at the lower end of the temperature range. Life is prolonged considerably at 5° and 10°C., is very much reduced at 0°C., while at 40°C., on the other hand, all the adults died within the first two days. At low temperatures all activity had ceased at 5°C., the adults remaining motionless on the floor, sides, and cork of the tube.

In explanation of the high mortality at 0°C. and lower temperatures, it will be remembered that in nature an insect makes definite preparations for facing very low temperature, which may or may not be instigated by climatic factors. Among them is the evaporation of a certain proportion of the free water contained in the body, enabling the insect to withstand freezing temperatures. In the present case, no such preparation was possible as transference to the low temperatures was accomplished too abruptly. Similarly, the conditions of the experiment were not such as to induce any storage of food material in the body against prolonged starvation, and although feeding was permitted prior to exposure, this did not provide sufficient nourishment for maintenance for any lengthy period. The early death of adults exposed to 0° and 5°C. therefore might more easily be due to starvation than to the effect of temperature.

The results of longevity experiments, considered by themselves, are not of very great value, but become significant and interesting only when the curve obtained is compared with that showing oviposition under similar environmental conditions.

(*c*) **Influence on Oviposition.**

The duration of oviposition at temperatures varying from 15° to 40°C. is represented graphically by a hyperbola (fig. 8), which also shows the increase in velocity

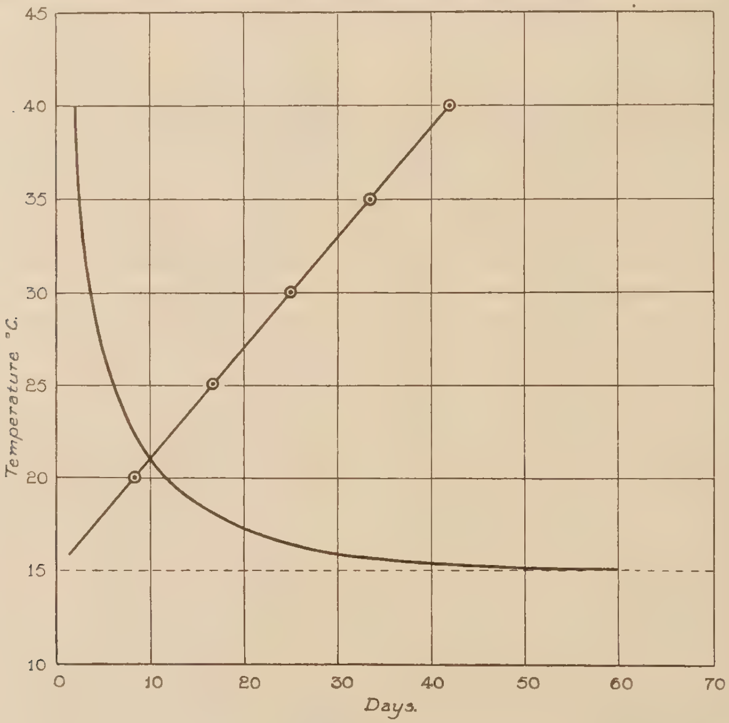


Fig. 8. *Microplectron fuscipennis*: Duration and velocity of oviposition at different temperatures and at constant optimum humidity.

of oviposition with rising temperature. The data for the construction of the curves were obtained with 48 females in each temperature series. The curves should be consulted in conjunction with the data contained in Table III, which gives the total number of eggs per female deposited, and the number of hosts utilised during the time occupied by oviposition at each individual temperature.

TABLE III.

Oviposition and Utilisation of Hosts by Microplectron fuscipennis *at different Temperatures.*

Temperature °C.	No. of ♀♀	No. of hosts used	Nos. per ♀ of	
			Hosts	Eggs
20	48	64	1·3	24·5
25	48	42	0·9	23·8
30	54	64	1·2	25·7
35	48	51	1·1	26·3
40	48	7	0·2	1·4

It will be seen that from 20° to 35°C. the increase in temperature was not followed by any significant difference in either the total number of eggs deposited by a female or the total number of hosts utilised for oviposition. At the same time the velocity curve shows clearly that oviposition was accelerated as the temperature increased, so that at 20°C. we find that 12 days are required, whereas at 35°C. approximately the same number of eggs are deposited in the three days occupied in this activity. The same percentage parasitism of the host occurs in both cases. Hence, so far as oviposition itself is concerned, a difference of 15° within this particular temperature zone has made no difference to the ultimate efficiency of the parasite in controlling the host, although the time required to do so is four times as great at the lower temperature. To say whether the latter point has any significance in the natural control of the host in the field would require an investigation of the reaction of the host to temperature, which is outside the scope of the present paper. It is hoped to deal with this at a later date.

It is frequently assumed that a combination of circumstances which lead to decrease in the longevity of an insect must necessarily result in a corresponding decrease in the number of eggs deposited by a female, and hence to a lowering of the efficiency of the parasites. If a comparison is made between the data presented by the curves in figs. 7 and 8 and in Table III, it will be seen that this is not the case with *Microplectron*. Ruling out the lower and higher temperatures causing functional inactivity, the very wide variation in the length of adult life shown between 15° and 35°C. has no direct correlation whatsoever with the ultimate production of eggs. This holds good throughout the rising temperature range until 40°C. is reached, which for all practical purposes must be looked upon as a lethal temperature.

In addition general activity increases with the temperature in the same manner as oviposition and may be expected to be correlated with a better and more wide dispersal of the parasite in space and hence to a more widespread attack upon the general host population.

(*d*) Influence on the Developmental Period.

Calculated in accordance with the thermal constant theory the threshold of development of *Microplectron* lies at approximately 8·3°C., and this, in the absence of definite experimental evidence to the contrary, may be taken as the point where activity commences on a rising temperature. The hyperbola (fig. 9), together with its reciprocal of velocity, presents the data obtained in a series of experiments on the developmental period at different temperatures. Fifty parasitised cocoons were used in each series at a saturation deficiency of 3 mm. mercury. Treatment prior to exposure was identical with that described under the corresponding experiments with humidity. As before, the developmental period discussed here includes the incubation of the egg and the larval and pupal periods.

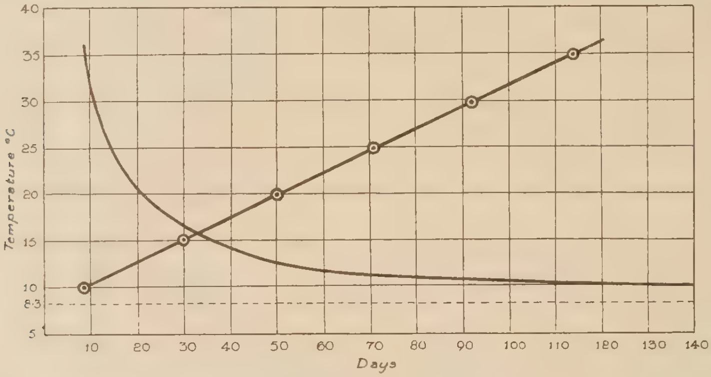


Fig. 9. *Microplectron fuscipennis*: Length and velocity of developmental period (egg-adult) at different temperatures.

Above 15°C. development is accelerated rapidly by increase in temperature, so that a difference of 5° from the point mentioned nearly halves the time from oviposition to the emergence of the adult from the cocoon of the host. From 20°C. the velocity is less, a further increase of 10° is required to halve the time again. The upper thermal limit proved to be in the neighbourhood of 40°C., this temperature proving lethal.

(*c*) The Function of the Cocoon in Relation to Temperature.

It is clear from the foregoing that there is no control of the micro-climate comparable to that found in the case of humidity. It is perhaps hardly to be expected that the presence of a cocoon should exert any control over the temperature within it, as the material of which it is constructed is of poor quality as a non-conductor. The determination of the temperature of the micro-climate is opposed by the same barrier as was encountered with humidity, and it seems impossible to obtain accurate records, even with a thermocouple, on account of the rupture which is a necessary preliminary.

It is stated in the literature that the cocoon serves to protect the pupa from sudden changes in temperature. Weiss (1914), for example, maintains that this is so for Lepidoptera. This is probably true for relatively short periods of high temperature. In the present case parasitised cocoons, which had been kept at a constant temperature of 25°C., were submitted to a rapidly rising temperature in the same incubator and subsequently maintained at 40°C. for 12 hours, after which a restoration to the original temperature was effected. Both the parasites and the hosts were killed by this treatment. Any control exerted by the cocoon must be of a limited and very temporary nature. We must conclude that while humidity is not likely to prove adverse during the developmental period under natural conditions, atmospheric temperature is of first importance as a limiting factor at this time.

(*f*) **Resistance to Cold.**

No experiments were carried out on the resistance of the various stages of the parasite to temperatures below freezing. It is known that the insect occurs in countries (*e.g.* Sweden) where the minimum temperature is as low as −18·6°C. In Canada it has become established in an area where the temperature during winter attains a level nearly twice as low as that. Such temperatures are unattainable by ordinary laboratory methods. It is clear, however, that *Microplectron* is able to withstand a severe winter climate.

(*g*) **Summary of the Influence of Temperature.**

There is a very well-defined zone of favourable temperatures which under suitable conditions of atmospheric humidity gives rise to optimum functional activity. This zone ranges from 20° to 35°C. Within these limits a rising temperature is correlated with increased velocity of oviposition, although not with any increase in the actual number of eggs deposited by a female. The development of the parasite is also accelerated, while adult longevity decreases without any detrimental effect upon its efficiency as an agent of natural control. Increase in general activity, such as dispersal in space, also occurs, which tends to aid the parasite in its location of fresh host material. The threshold of development is situated at approximately 8·3°C., while the upper thermal limit or death point is, for practical purposes, at 40°C.

III. *MICROPLECTRON* IN RELATION TO CLIMATE.

In attempting to relate laboratory data to climate in the natural environment of an insect a very serious difficulty arises, due to the fact that we know practically nothing of the relation of the micro-climate to the surrounding atmospheric conditions. There is abundant evidence to show that the humidity of the micro-climate, say at the surface of a leaf, inside a fruit, or among pine needles on the ground, is very different from that of the atmosphere as recorded by meteorological methods. At the same time we have no standardised method of comparing the two situations. We do not know in what way they fluctuate in regard to each other. The significance of the micro-climate, especially with reference to adult insects, which can move from one place to another in accordance with their requirements, has already been emphasised. Again, in the case of the developing parasite we have seen that normal fluctuations in atmospheric humidity have little effect upon the micro-climate owing to the protection afforded by the cocoon. The difficulty of interpretation cannot be overcome until our knowledge has been extended, and in the meantime any attempt to base assumptions on meteorological data is therefore open to the possibility of error. Bearing this in mind, the following remarks are put forward with a certain diffidence, born of the lack of any but the usual climatic records for the natural surroundings of the parasite and its host.

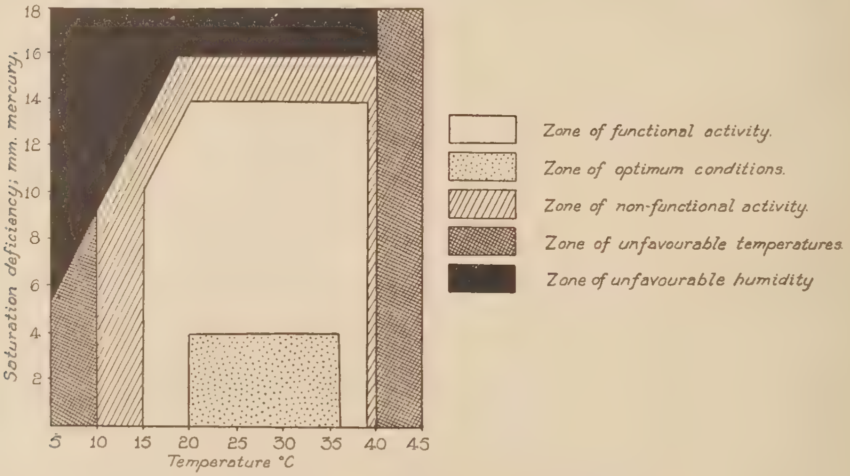
A consideration of the experimental evidence indicates that the optimum zone of combined temperature and humidity, wherein the parasite may be expected to achieve its maximum efficiency in the control of the host, lies between 20° and 35°C. and between a saturation deficiency of 4 mm. of mercury and saturation. An attempt is made (fig. 10) to express diagrammatically the relation of *Microplectron* to climate, as represented by atmospheric temperature and humidity. There is a reasonably close correlation between this and the available field records, as will be seen. It will be convenient to review here the respective climates of the areas which have been surveyed and then to examine them and the degree of parasitism found in the light of the data obtained in the laboratory.

Parasitism by Microplectron in Europe.

In the different localities in Europe which were examined by them, Morris and Cameron found that there was a considerable variation in the percentage parasitism of *Diprion sertifer* by *Microplectron*. Thus in Austria it was as low as 2–3 per cent., in Hungary it was from 10 to 15 per cent., while the highest record of 33–80 per cent. was attained along the eastern coastal region of the Adriatic in the neighbourhood of Fiume. Further records of the presence of the parasite on the Continent have come from Scandinavia, Poland, Holland and Germany, but definite figures are not available regarding the extent of parasitism in these countries.

Climate of the Adriatic Coastal Region.

Of the places mentioned above the climate of the Adriatic coastal region most nearly conforms to the optimum conditions shown in fig. 10, and it is significant that the highest parasitism coincides with this. In order to obtain a clear picture of this very favourable climate, a climatograph for Fiume is appended (fig. 11), which has been constructed from data given by Hann (1911). The summer climate is warm and there is an ample mean annual rainfall of 162 cm. (63·8 inches), which, together with a close proximity to the sea, makes for a moist atmosphere. This is reflected in the figures for the mean relative humidity in the different seasons of the year, which is given as 67 per cent. for the summer, 68 per cent. for the winter,



18
16
14
12
10
8
6
4
2
Saturation deficiency; mm. mercury.
5
10
15
20
25
30
35
40
45
Temperature °C
Zone of functional activity.
Zone of optimum conditions.
Zone of non-functional activity.
Zone of unfavourable temperatures.
Zone of unfavourable humidity

Fig. 10. *Microplectron fuscipennis*: Diagrammatic representation of the effect of atmospheric temperature and humidity on the parasite.

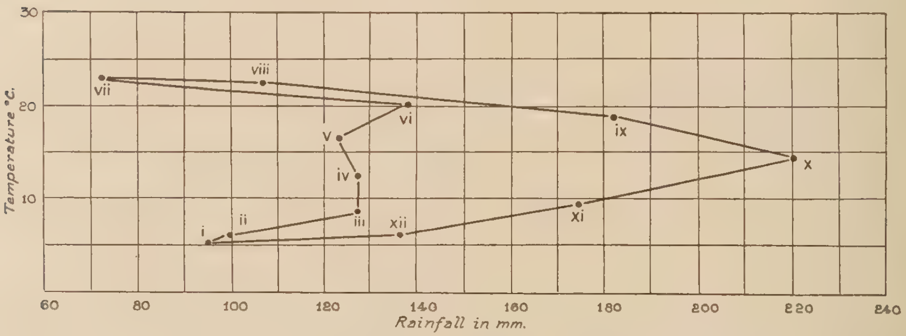


Fig. 11. The climate of Fiume, typical of the eastern coastline of the Adriatic, where parasitism by *M. fuscipennis* reaches its maximum in Europe.

and 68 per cent. for the whole year. The climate is thus continuously moist. A maximum temperature of 33°C. is attained in July, during which month the mean temperature is 22·9°C. Optimum conditions for the parasite occur during June, July and August, but functional activity (oviposition) is favoured from May to September. The minimum temperature is given as —4·4°C. and the mean minimum as 5·3° during January.

Climate of the Hungarian Region.

Further north, in Hungary, the summer climate differs to some extent from the foregoing, especially as regards humidity. Budapest, which is near the site of the field operations quoted above, has the same maximum temperature as Fiume. The mean monthly temperature, however, is somewhat lower, that for July being 21·6°C. The minimum temperature is —12·2°C. Optimum conditions are again found in June, July, and August, and conditions favourable for functional activity from May to September ; but the actual periods are shorter than near the Adriatic. The zone of favourable temperature comes into operation later in May and ceases earlier in September. The district is remote from the sea and therefore has not this valuable additional source of atmospheric humidity. The annual rainfall is in the neighbourhood of 59 cm. (23·23 inches).

Climate of the Austrian Region.

The Austrian figures for parasitism were obtained near Vienna. The climate here is again a little different from that of Budapest, and although the maximum temperature attained is the same (33·2°C.) the mean monthly temperatures during the summer months are approximately 2° lower, that for July being 19·6°C. The optimum temperature zone extends from about mid-June to the middle of August, while the zone of functional activity covers the period from early June to early September. There is thus a further shortening of the favourable breeding period as compared with that found in Hungary. The annual rainfall is higher than that of Budapest. This area, in common with the Hungarian region, is protected from the moisture-laden winds from the sea by mountain ranges.

Climate of Other Regions where Microplectron occurs.

In the absence of definite records of parasitism in other parts of Europe and in default of information as to exact localities it would be premature to attempt to consider the relationship existing between parasite and climate in those areas ; but in order to make the present discussion as complete as possible, we may examine very briefly the climate of a few chosen localities in the regions where *Microplectron* is known to occur. In Poland the parasite has been recorded from the neighbourhood of Posen, which has a maximum temperature of 32·2°C., a minimum of —16·8° and a mean monthly maximum of 18·6°C. in July. The optimum zone includes the month of July alone, while functional activity can occur from early June to late August. There is a low mean rainfall of 49 cm. (19·3 inches). In Germany no locality is specified in the literature available to the writer. In general the climate may be said to be very similar to that of Poland, with the exception of the annual rainfall, which is a good deal higher. The periods of activity may be taken as following closely those stated for the latter country. In Holland the mean monthly temperatures are lower (that for Utrecht, for example, being 17·0°C. in July) and the period of functional activity is reduced to between about mid-June and the latter part of August. The rainfall is much the same as in Germany. Sweden has a still cooler climate. Taking Stockholm as an example, the mean monthly temperature for July is 16·7°C., while the maximum of 28·6° is the lowest of those with which we have dealt. The minimum temperature is --18·6°C. Here the optimum period is confined to a part of July, while functional activity is restricted to a relatively short period from July to the middle of August. There is a moderately good rainfall.

The Correlation between Climate and Parasitism.

The difference between the efficiency of the parasite as observed in the Adriatic region on the one hand, and in the Austrian region on the other, is so remarkably wide that it demands some attempt at a satisfactory explanation. In seeking a solution one naturally turns, first of all, to climatic considerations. At first sight there does not appear to be a sufficiently wide variation in the conditions obtaining in the two areas to warrant such a striking disparity in the degree of control exerted by the parasite ; yet a close study reveals that such climatic differences as do exist are enough to account for a large part of this difference in parasitism, although perhaps not the whole of it. For convenience of reference the climates of the three European regions that were investigated are summarised in Table IV.

TABLE IV.

Summary of Climate at Places from which Records of Microplectron fuscipennis *have been made and its Relation to Parasite Activity.*

Region	Locality	Rain-fall, cm.	Temperature °C.				Optimum activity	Functional activity
			Max.	Min.	Mean max.	Mean min.		
Adriatic ...	Fiume ...	162	33·0	−4·4	22·9	5·3	June-August	May–September
Hungarian	Budapest	59	33·2	−12·2	21·6	−2·1	June–August	Late May–early September
Austrian ...	Vienna	83	33·2	−14·6	19·6	−1·7	Mid-June–mid-August	Early June–early September

In the first place, the humidity of the atmosphere along the eastern slopes of the Adriatic is much higher than that in the Austrian region. This is due partly to a heavier rainfall and partly to the influence of wind-borne moisture from the sea. In view of the marked influence of humidity upon the oviposition of *Microplectron* exhibited under laboratory conditions, this in itself is an important reason for the higher parasitism of the Adriatic region.

Turning to temperature, we have already seen that the actual period which is favourable to functional activity is shorter in Austria than along the Adriatic, the zone representing these conditions coming into operation later and ending earlier. Actually the differences are perhaps as much as a month at the beginning and two to three weeks at the end of the season. The period occupied by the optimum zone is correspondingly shortened and becomes approximately two months instead of three. Taken in conjunction with the lower mean temperature prevailing generally throughout the summer, the resultant effect upon the parasite is to slow down increase in its population, both at the important initial stage, when the building up of the population is commencing, and also throughout the remainder of the breeding season. In this connection it must be remembered that small changes in temperature, of a few degrees, have a very marked influence on the velocity of oviposition and development of the parasite, and especially is this so within the optimum temperature zone.

There is thus good evidence for crediting a large part of the observed disparity in parasitism to the account of climate. At the same time the possibility that other factors may contribute to the phenomenon must not be disregarded. Morris and Cameron have suggested that it may be influenced by availability of the host material and have noted that, whereas in the Adriatic region the majority of the host cocoons are constructed on the trees and are thus freely exposed, in Austria the greater proportion are to be found buried beneath the fallen pine needles on the forest floor.

The true significance of this in relation to the facts under discussion can only be arrived at by studies on the host-relationships of the parasite. It is hoped that this will be elucidated in the near future. The true explanation of the variation in parasitism most probably lies in some combination of the two factors.

Prediction of Areas suitable for Microplectron.

An attempt to predict the possible range of a parasite on any large scale can only be tentative. Difficulty arises in that large variations in climate may occur between different districts in the same country. For the present it will suffice to confine attention to the general situation obtaining in Europe and North America, and to endeavour to determine the possible distribution of the parasite in the two Continents in the light of the evidence already adduced.

The plan adopted has been to determine the summer limits of temperature within which parasite activity is reasonably good and to use rainfall maps as a guide to humidity. The northern limit was determined arbitrarily by following the summer isotherm for 60°F., while the zone of parasite activity was taken as lying between this and the isotherm for 80°F., in the south. Within this zone, further limits are imposed by conditions of inadequate atmospheric humidity, and these have been delineated with the aid of rainfall maps.

The construction of distribution maps of this description is open to criticism in that within the favourable zone shown thereon some districts or localities will have too high a maximum temperature or too low a humidity. Similarly, in the unfavourable zone many places will be found to possess a climate which is in every way suitable for the parasite on account of altitude or higher local precipitation. The map, therefore, must be regarded as the expression of generalisations only, giving a composite picture of the situation. For special cases the chart in fig. 10 should be consulted together with the meteorological data for the locality in question.

Actual and Possible Distribution in Europe.

On the first of the accompanying maps (fig. 12) the areas from which *Microplectron* has been recorded are indicated by oblique lines, and where parasitism was high by cross-hatching. Stippling has been used to indicate those areas in Western Europe where the parasite might be expected to occur in the presence of suitable host material. It will be noticed that the possible distribution over the major portion of the Continent and absence of records of the presence of the parasite can only be due to lack of sufficient investigation in the countries concerned, or to lack of the suitable host. The absence of pine or spruce is a factor which has not been considered in preparing the map, as sufficient data on the distribution of the trees were not available. Further studies on the parasite-host relationships may reveal some peculiarity in the life-cycle of the host in certain districts, which may render the appropriate stadium unavailable during the period of the year when the parasite might be expected to be most active, and hence reduce the parasitism to so low a level that it would not be noticed except during intensive investigations.

The only accurate figures of parasitism by *Microplectron* available to the writer are those of the Farnham House staff who have investigated the position in Austria, Hungary, and Jugoslavia. It is as well to mention here that although *Microplectron* has been recorded so far only from *Diprion sertifer*, *D. pini* and *D. pallidus* and therefore follows the distribution of these hosts in Europe, there is good reason for supposing that it has alternate hosts which are, as yet, unrecorded. It is only natural to look to the other sawflies to provide these, and in the future it is probable we shall find that, among others, *D. polytomum* must be added to the list. An explanation of the fact that the parasite has not emerged from collections made in the past has been offered by Morris & Cameron (1935). The position may be made more clear when it is realised that this sawfly was almost invariably collected in the larval stage and allowed to pupate away from exposure to attack by pupal parasites. Only very small collections of pupae have been made and these were quite inadequate as a basis from which to argue the presence or absence of any one parasite. In consideration of the ease with which parasitism of *D. polytomum* cocoons

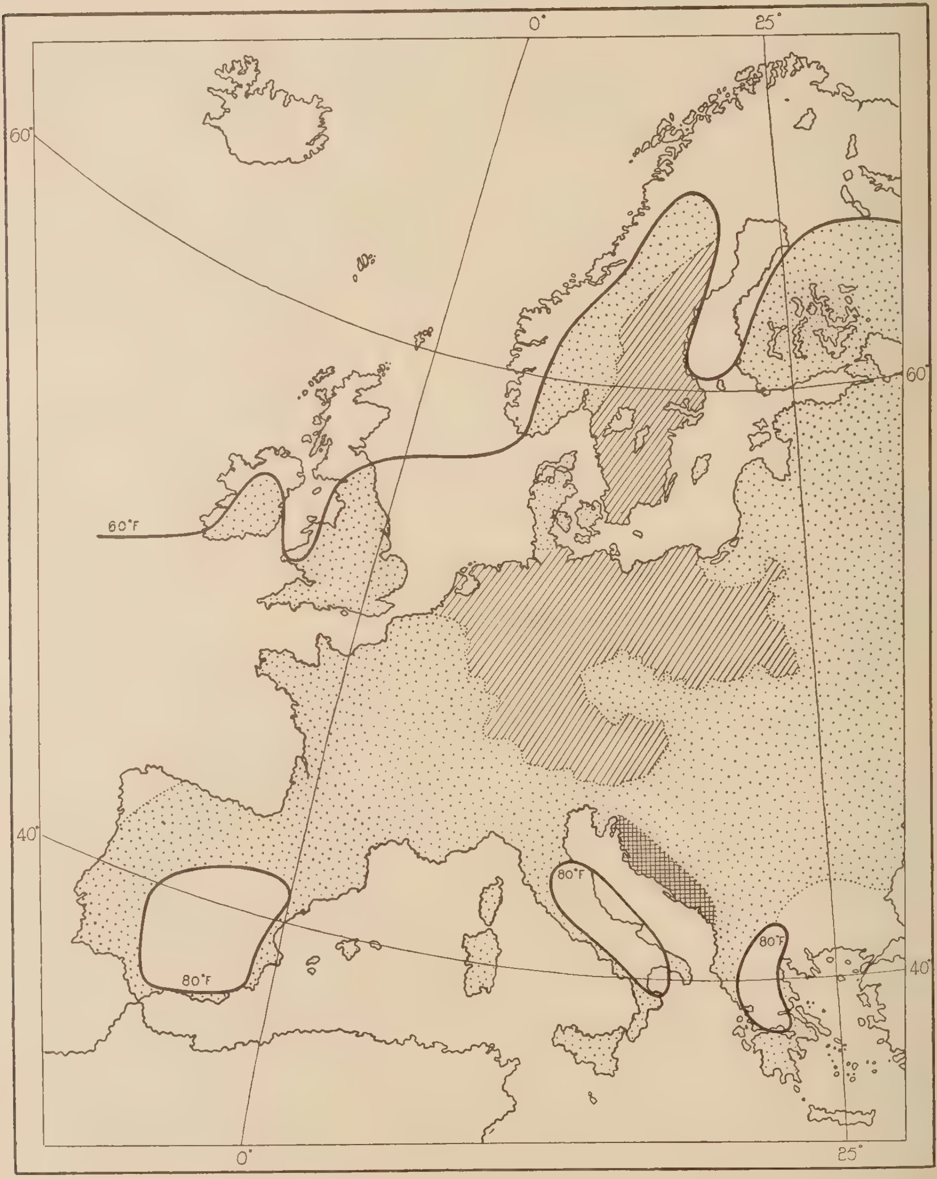


Fig. 12. Map showing the actual and possible distribution of *Microplectron fuscipennis* in Europe. The oblique lines indicate the known distribution and the cross-hatching shows where parasitism attains its maximum on the Continent. The possible distribution of the parasite is indicated by stippling.

can be attained in the laboratory and of the establishment of *Microplectron* on the species in Canada, it is fairly safe to assume that the parasite does attack it in Europe, and that it is only a matter of time before this is found to be the case. This explanation holds good for the absence of records from such countries as, for example, Czechoslovakia—a country which possesses a climate suitable for the development and activity of the parasite. Here *D. sertifer* was absent from the areas examined, but *D. polytomum* occurred in numbers sufficiently large to provide a favourable breeding-ground for the parasite.

Possible Distribution in Canada.

The Spruce Sawfly (*D. polytomum*) was first observed in the Gaspé Peninsula in 1930 (Balch & Simpson, 1932) when it was causing widespread damage. In 1931, 2,000 square miles were affected. This had increased to over 4,000 square miles by 1934 (Balch, 1934) and was extending into New Brunswick. *Microplectron* was released in Canada in the summer of 1934 and recoveries were made in at least three localities during the present year (1935). In view of the rapid spread of the Spruce Sawfly it will be useful to consider the possibility of the parasite following in the train of its host. A map (fig. 13) is presented, based upon the climatic data available and constructed on the same general plan as that for Europe.

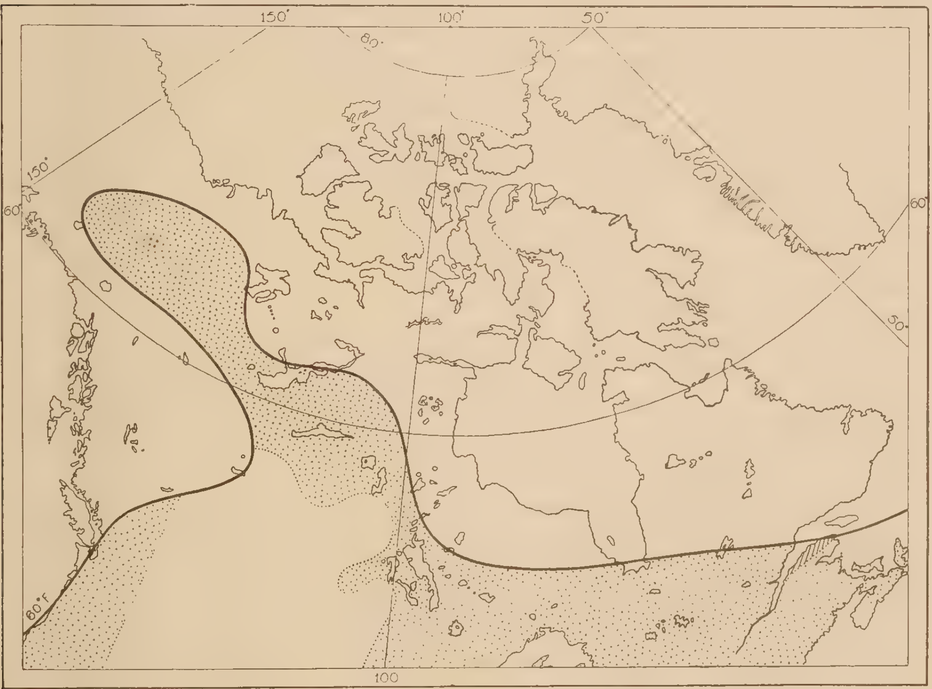


Fig. 13. Map showing the possible distribution of *Microplectron fuscipennis* in Canada.

As the sawfly is spreading southward into an area having a more favourable climate for parasitic activity, we may expect *Microplectron* to follow the present trend of dispersal evinced by the host and to give higher records of parasitism in New Brunswick than in the Gaspé Peninsula, which is very near the northern limits of favourable temperature. Favourable conditions also occur over nearly the whole of the southern half of Canada, with the exception of the desert region towards the west.

IV. Summary.

1. The influence of atmospheric humidity on the various stages in the life-cycle of *Microplectron fuscipennis*, Zett., is examined. Both the longevity of the adults and the extent of oviposition are found to be proportional to the saturation deficiency of the atmosphere. Under favourable temperature conditions, functional activities are at their maximum in a moist climate, but a wide tolerance is exhibited so far as oviposition is concerned. At normal humidities no effect on the developmental period of the parasite is apparent when the humidity is varied, and this is shown to be due to the protection afforded by the host cocoon.

2. Temperature affects the parasite in a normal manner. The threshold of development is approximately at 8·3°C., and the zone of functional activity is from 15° to a little over 35°C. Optimum conditions for oviposition and development occur between 20° and 35°C. Death occurs at 40°C., while at the lower temperatures, near freezing point, starvation of adults takes place after a lengthy exposure. The hibernating parasite can withstand temperatures very much below freezing point, field records coming from countries where the winter temperature falls to so little as −37°C.

3. The relation of *Microplectron* to climate is discussed and an explanation is offered of the wide variation in natural parasitism occurring in European countries.

4. The actual and possible distributions of the parasite in Europe are discussed and a map is presented depicting the position as known at present.

5. The possible distribution of the parasite in North America, after liberations have been made, is dealt with and it is shown that the present trend of dispersal of *Diprion polytomum* is in the direction of climatic conditions that are more favourable to the parasite than are those in the area where the parasite has already become established.

References.

Balch, R. E. (1934). The European Spruce Sawfly (*Diprion polytomum*, Hartig).—Spec. Circ. Div. For. Ins. Dept. Agric. Canada, no. 8, 3 pp., 1 pl.

—— & Simpson, L. J. (1932). A European sawfly (*Diprion polytomum*, Hartig) attacking spruce in the Gaspé Peninsula, Que.—Canad. Ent., **64,** no. 7, pp. 162–163.

Buxton, P. A. (1931). The measurement and control of atmospheric humidity in relation to entomological problems.—Bull. Ent. Res., **22,** pp. 431–447.

——. (1932). Terrestrial insects and the humidity of their environments.—Biol. Rev., **7,** no. 4, pp. 375–420.

—— & Lewis, D. J. (1934). Climate and Tsetse Flies : Laboratory studies upon *Glossina submorsitans* and *tachinoides*.—Phil. Trans. Roy. Soc., **224** (B), pp. 175–240.

Darby, H. H. (1933). Insects and micro-climate.—Nature, **131,** p. 839.

Hann, J. (1911). Handbuch der Klimatologie.—Stuttgart.

Janisch, E. & Abdel Aziz Ali Elsayed Ghabn. (1933). Ueber den Einfluss der Luftfeuchtigkeit auf die Entwicklung junger Seidenraupen.—Arb. biol. Reichsanst. Land- u. Forstw., **20,** pp. 245–257.

Kennedy, C. H. (1927). Some non-nervous factors that condition the sensitivity of insects to moisture, temperature, light and odors.—Ann. Ent. Soc. Amer., **20,** pp. 87–106.

LEAN, O. B. (1931). The effect of climate on the migrations and breeding of *Locusta migratorioides* in Nigeria.—Bull. Ent. Res., **22,** pp. 551–569.

LEESON, H. S. (1932). The effect of temperature and humidity upon the survival of certain unfed rat fleas.—Parasitology, **24,** pp. 196–209.

MACGILL, E. I. (1931). The biology of Thysanoptera with reference to the cotton plant, vii. The relation between temperature and humidity and the life cycle.—Ann. Appl. Biol., **18,** pp. 574–583.

MAERCKS, H. (1933). Wird der Wasserhaushalt der Insekten durch das Daltonsche Gesetz bestimmt ?—Anz. Schädlingsk., **9,** pp. 66–68.

MELLANBY, K. (1932). Effects of temperature and humidity on the metabolism of the fasting bed-bug (*Cimex lectularia*), Hemiptera.—Parasitology, **24,** pp. 419–428.

MORRIS, K. R. S. & CAMERON, E. (1935). The biology of *Microplectron fuscipennis* Zett. (Chalcid.), a parasite of the Pine Sawfly (*Diprion sertifer,* Geoff.)—Bull. Ent. Res., **26,** pp. 407–418.

ROUBAUD, E. (1933). L'anhydrobiose désertique et son influence sur le cycle annuel du criquet pèlerin (*Schistocerca peregrina*).—C. R. Acad. Sci. Fr., **196,** pp. 1139–1142.

URECH, F. (1890). Chemisch-analytische Untersuchungen an lebenden Raupen, Puppen und Schmetterlingen und ihren Secreten.—Zool. Anz., **13,** pp. 254–260, 309–310, 334–341.

UVAROV, B. P. (1931). Insects and Climate.—Trans. Ent. Soc. London, **79,** pp. 1–247.

WEISS, H. B. (1914). Thermal conductivity of cocoons.—Psyche, Camb., Mass., **21,** pp. 45–50.

INVESTIGATIONS ON *TRICHOGRAMMA LUTEA*, GIR., AS A PARASITE OF THE COTTON BOLLWORM, *HELIOTHIS OBSOLETA*, FABR.

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I. Preliminary Considerations.

Trichogramma lutea, Gir., is an indigenous parasite of the eggs of *Heliothis obsoleta* in South Africa. In 1930 the authors undertook investigations on the mass production and experimental releases of this parasite with a view to using it in the control of bollworm. The work has been in progress for four years.

The original technique evolved by Flanders[2] in California for the mass production of *Trichogramma minutum*, Riley, in the eggs of the Grain Moth, *Sitotroga cerealella*, Oliv., was adhered to largely in breeding and multiplying *T. lutea* for our purposes. Certain races of the parasite have been encountered which do not parasitise the eggs of the common grain moth, however, and in testing these other hosts were used, notably the eggs of the cutworm moth, *Agrotis segetum*, Schiff.

The principal aim in the breeding measures was to multiply and maintain only sufficient numbers for the requirements of field and laboratory experiments, and although at times these called for a production of a million parasites a day no special difficulties were met with. Difficulties were, however, experienced in the evaluation of the activity of the released *Trichogramma*, and the first two years of work were spent mainly in defining and investigating some of the problems involved in the estimation of parasitism in egg populations. These problems have been interpreted as follows :—

Effective Parasitism.

Various agencies play a part in destroying large numbers of the deposited eggs. Predators are always present and may be predominantly represented in the insect community associated with a particular crop. Climatic and agricultural, as well as insect factors, operate directly or indirectly to destroy eggs, such factors always having a fluctuating effect in reducing their numbers. Of the remaining, or surviving, eggs a variable portion is infertile and some fertile eggs do not develop to the point of eclosion. The portion that hatches under natural conditions may be termed the " active fraction " in so far as it contributes larvae, and the value of egg parasites depends upon the extent to which they parasitise these otherwise effective eggs. Thus it would seem that to measure parasite activity in this respect the number of eggs normally surviving under the given conditions and the number of these that become parasitised both require to be known with a high degree of accuracy. To attain this end, daily records of the history of individual eggs as laid *in situ* on numerous observation plants in any experimental area would be needed.

It is clear that to procure a guide to the degree of parasitism, eggs must be left where laid and marked to observe events. Apart from the eggs, parasitised or otherwise, which are destroyed on the plant, any sample of undated bollworm eggs *collected* from plants contains eggs ranging in age from a few hours to several days, with consequent differences in the length of time of exposure to parasitism. Bollworm eggs that are mainly 48–60 hours old may be parasitised to the extent of 70 per cent., whereas a collection composed largely of eggs laid in the previous 24 hours may contain very few parasitised eggs ; yet it would seem that calculations of parasitism are based frequently on evidence obtained from small and discontinuous collections.

An increase in the parasitism of the total " parasitisable " eggs (fertile bollworm eggs less than 60 hours old) present at any period in the course of oviposition does not necessarily mean an augmented parasitism amongst the eggs destined to escape destruction by some predatory or other agency. Hence estimates of effective parasitism should be based only on known parasitised eggs in the surviving or active fraction, and before significance can be attached to these estimates, values for them must be sought in comparative computations of resulting larvae.

These considerations were perceived early and experimental procedure giving expression to them was adopted.

Oviposition by Heliothis obsoleta.

The preliminary field trials were misdirected through inadequate knowledge of the habits of the egg-laying moth. A discontinuity of oviposition on cotton was noted that seemed due to a transference of moth activity, periodically, to other food crops. Occurrences of this nature frequently interrupted the progress of early release experiments, which were founded on the assumption that several generations of bollworm would eventuate in the same crop, especially long-standing crops like cotton. As a prelude to further work with *Trichogramma*, therefore, a study of the food-plant associations of *Heliothis* was undertaken. As since reported[5], it was found that oviposition by this moth principally occurs at the period of bud and flower production of all the hosts surveyed then, and more extensively later, by the Cotton Insect Pest Survey at Barberton. These investigations showed when liberations of *T. lutea* should be made in order to conform with the course of oviposition. At the same time certain food-plant preferences of the *Heliothis* moth came under observation. These are strongly exhibited and in an area of mixed cropping, such as that under review, bring about diversion of moth activity, suddenly at times, from one food crop to another more favoured by the egg-laying moth. For example, maize, on coming into tassel, generally exhibits a stronger attraction than cotton. These are the two principal crops concerned in the rainy season ; but there are others in smaller acreages that, together with weed hosts, exert attraction in varying degrees. Thus, for the purpose of testing *Trichogramma*, it was ultimately learned that crops required to be selected rather carefully, both with regard to their flowering periods and the juxtaposition of other crops.

Oviposition by *H. obsoleta* is unevenly distributed over areas of food-plants. Portions of most cultivated lands in South Africa have been eroded to some extent, leaving in them more or less broad and irregular patches where plant growth is comparatively meagre. Eggs are rarely found on plants so situated. Elsewhere in a field wide differences exist in the size, vigour, and fruiting of the crop in response to variations of soil and treatment. It has been found [4,5] that the egg-laying in question is concentrated in the better grown, most vigorous and freely fruiting portions. Even within these a preference is shown for the best plants in point of size and fruiting, as correlations determined here between size of plant and egg numbers gave a positive correlation of $r = 0{\cdot}370$ with $P < 0{\cdot}01$. Large fruitful plants are apparently somewhat more attractive than those of a vegetative type, as indicated in this case by a correlation coefficient of $+0{\cdot}24$ with $P < 0{\cdot}01$. These relationships suggested where *Trichogramma* should be liberated in a crop and the knowledge was utilised subsequently.

Dispersion of Trichogramma lutea.

The use of laboratory-bred *Trichogramma* presupposes, to a considerable extent, that concerted action by large numbers will occur near the point of liberation. A primary consideration was to procure some knowledge of the distance and rate of spread from points of liberation. The dispersion range depends no doubt on various influences such as atmospheric conditions, light intensity (this is a dominating factor influencing the insect's activity), abundance of hosts, type of plant growth, wind direction, force, etc. In attempts to arrive at some conclusions on dispersion behaviour, observations of the following nature were conducted. Various fields of cotton, maize and beans, were taken as representing three main types of food-plant of the bollworm. Within these, from the centre, a series of circles was marked off dividing the whole of the field into zones. From the common centre eight radii were projected to the circumference of the outermost circle. These, marked by flags on the boundary of every circle, divided the zones into segments, within each of which a systematic sample of marked plants was taken—proportionate to the area enclosed—for egg and parasitism records. Fields showing the presence of naturally-bred *Trichogramma* were discarded.

When oviposition in quantity was known to be in progress, parasites at the rate of 5,000 per acre, or multiples of this, were allowed to escape from containers placed in the centre of the field, one release being made. Target diagrams of the layout of the circles and marked plants were prepared showing the approximate position of all parasitised eggs recorded within seven days following release. These showed the extent of parasitism in the zones at increasing distance from the centre of the field. The circles were divided into segments to note the direction of drift should the parasites be deflected by wind, the prevailing wind being north-east. It was hoped from these and similar tests to obtain some idea of the size and shape of the field required for liberation experiments and to obtain a clue to the number of females needed per unit area in order to bring about a continuously high parasitism, as for example 70 per cent. and upwards. The aims of the inquiry were realised in part. It was clear that dispersion was widespread and rapidly so, the evidence being that numbers must have penetrated to the outer zone of small fields (4–5 acres) within 24 hours of release in the crop. Doubtless many left the crop in the same period and later evidence points to this having occurred even from much larger fields.

Concerted activity in small areas did not materialise, but it seemed that in choosing large, square fields, parasites which are centrally released would remain largely within their boundaries.

The diagrams from cotton and maize showed no central concentration of parasitised eggs, but relatively dense grouping did occur sometimes to one side of a field or at different points in the same field. Included in the former were occasions when the *Trichogramma* appeared to have travelled before gentle to moderate breezes (Beaufort's Scale), the targets showing a cone-shaped distribution. Apart from the evidence that dispersion was unexpectedly rapid and diffuse, the main information provided was that concentration of parasitised eggs coincided with areas of heavier oviposition. More extensive parasitism in these places could be due to many fewer *Trichogramma* than were present elsewhere in the crop where oviposition was light. This point was further tested on finding that the laying on irrigated bean crops was fairly evenly distributed, probably because, with ample moisture, growth and fruiting were more uniform. Here there was a concentration of parasitism about the point of liberation, although dispersion in all directions was evidenced.

The largest number of *Trichogramma* liberated in the dispersion trials was 10,000 per acre. Using this quantity in irrigated bean crops, the parasitism in the concentrated area attained to 80 per cent. of the recorded eggs. These crops afforded the most satisfactory testing areas and, given this high return, it was decided to employ the same quantity in subsequent experiments. Although the issue of such large numbers to even a small farming community was not contemplated as a practical measure, it seemed advisable, and probably time-saving, to investigate their effects, later reducing the quantities liberated, if need be, rather than to work with increments.

In view of the information gained as above, in the earlier methods of approach to the general problem, it was clear that one could expect to find a wide variation of circumstances in any field of a crop utilised for release work. At the same time the variables present offered a fruitful means of studying the value of *Trichogramma* as, by dividing *chosen* areas of crop into many small blocks and taking intensive records on adequate samples of material in each, a wide range of results would accrue for comparison. Depending on the size of the field and block unit, experiments in single crops could each contribute up to a hundred or more individual cases wherein all the factors from initial egg population to final larval numbers had been closely appreciated.

The results presently reported were derived from a final series of tests designed on such a block system. The examples presented are from trials that proceeded without hindrance from unfavourable weather conditions or lack of host material and to that extent bear an optimum character. The degrees of parasitism obtained were also rather better than the average.

II. Natural Parasitism.

As *T. lutea* is an indigenous parasite of *Heliothis obsoleta*, continuous observations have been made on the parasitism due to the naturally-bred representatives. During the last two years these records have been taken as a routine part of the work of the Cotton Insect Pest Survey, so that adequate data are available for comparing the levels of parasitism occurring naturally with those accomplished experimentally. Some comparisons are drawn later.

Records on natural parasitism found in the immediate neighbourhood of an experimental release area, up to the time of the first liberation, were relied upon to furnish an estimate of the extent of any reservoir of naturally-bred *Trichogramma*, some of which might enter the crop of record when eggs were present. By choosing early rain-grown crops which were distant from others where insect activity was still concentrated on irrigated lands, the complication of an influx of " wild " stock was found to be greatly reduced. Some influx might, however, be expected from *Heliothis* and from the eggs of other insects on weeds in and around the selected fields. Actually, in the examples to be quoted from cotton and maize, only laboratory-bred material contributed to the results. As referred to later, the situation in irrigated crops was otherwise.

For purposes of discussion, the work may be divided into summer and winter experiments. In the winter season, which is cool and dry, various vegetable and orchard crops are produced under irrigation. These are scattered, relatively small patches that occupy insular positions in the midst of the dried vegetation of the veld. The activity of *Heliothis* moths emerging in the winter-spring seasons is mostly confined to these irrigated crops and associated weeds, and they form the principal breeding-ground of the bollworm that attacks the succeeding rain-grown crops in the summer. Attempts to exploit *Trichogramma* have therefore been made in both phases of the agricultural practice.

III. Materials and Methods.

Rain-grown Summer Crops.

Fields were divided into one-quarter acre blocks and a random sample of 16 plants was taken in each for purposes of recording the parasitism or other history of the eggs laid. Successive additional plant samples of the same order were utilised for larval counts. Apart from other considerations, the division of fields into many blocks permitted a valid estimate of egg and larval populations. Although the laying was unevenly distributed, as previously discussed, subsequent computations* of data for the parameters Y_1 and Y_2 after Fisher[1] showed that the distribution in individual plots conformed to the normal curve. Estimates of the sampling error, therefore, could be determined as for a normal distribution, thus giving point to expressions of population numbers on a basis of unit area.

Eggs on leaves and stems were marked by inserting a pin bearing a coloured, glass-beaded head into the underlying plant epidermis. Pins with different coloured heads were used on each day of record to distinguish between successive ovipositions. At points where pins were unsuitable pieces of thread or cardboard tags of the appropriate colour served.

In a number of the central blocks surrounding the points of release, the fate of each marked egg was determined on daily examination and ultimately classified as hatched, missing, destroyed, infertile, or parasitised. A differentiation between missing and destroyed was generally possible, as the collapsed shells of eggs sucked out by predators (chiefly Anthocorids) commonly remain adhering to the plant. Undetermined eggs, such as those classed as "missing," were comparatively infrequent and it was considered that this procedure enabled the determination of the active fraction of the eggs as previously defined. A factor for this, expressed as a percentage, was calculated on daily data for the oviposition in several of the central one-quarter-acre divisions. The factor so obtained was applied to the eggs counted in the remaining blocks of a field where it was not possible to make daily observations. In all of these latter, eggs were marked twice-weekly for records of known parasitism. In addition, eggs on weeds and on the nearest cultivated crops were observed twice-weekly, both before and during a test, in order to obtain information on the status of natural parasitism locally.

Samples of eggs were collected frequently to ascertain if a parasite other than *Trichogramma* was present.

The *Trichogramma* for release were bred in fresh *Sitotroga* eggs that had been scattered uniformly over a film of gum tragacanth on squared paper pasted upon cardboard sheets, the sheets being divided according to the number of parasites for issue. For the greater part emergence and fertilization took place in the laboratory before liberation. Freshly parasitized eggs were used always in field trials, as the authors found a diminution of vigour and longevity resulted in material cold-stored for any period.

Breeding stocks were renewed each season. The subject was not investigated extensively, but at least two and probably three races of *Trichogramma* are present in the Transvaal. There is no morphological distinction between two of these, but one is slightly darker in coloration in the inter-segmental regions of the abdomen. They did not interbreed in confinement and reacted differently to host eggs. The darker race, which did not parasitise *Sitotroga* eggs, is much less abundant in the cultivated areas and is less prolific than the other. Petersen[6] has reported similar circumstances regarding the presence of two strains of *T. minutum* in New Jersey. A third type has been taken on rare occasions from *Heliothis* eggs. This is uniformly light lemon-yellow in coloration and readily parasitized *Sitotroga* eggs. We were unable to cross it with the more common strain although, owing to lack of numbers and replicated trials, this may have been due to females refusing the males. It is possible that further study would establish the presence of genetically diverse forms, as reported by Harland & Atteck[2] in the West Indies. The common type was multiplied for the present work. Releases were made twice-weekly during oviposition by the bollworm moth.

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* Forthcoming publication on methods of sampling insect populations in the field by Mr. Joseph Marshall, Cotton Experiment Station, Barberton, Transvaal.

It may be stated here that there is considerable inequality in numbers of the sexes of *T. lutea* when bred in different host eggs. This subject was explored, as it has an important bearing on the exploitation of laboratory-bred parasites. Our findings were that in over 20 successive generations bred in *Sitotroga* eggs the mean percentage of females was 62. The differences between the means of the generations were not significant. Using the same stock of *Trichogramma* and *Heliothis* eggs as host for a similar period, practical equality of the sexes ensued, males or females predominating slightly. In the case of cutworm eggs, under the same conditions, a consistently great preponderance (79–90 per cent.) of females obtained. In the present instances the rate of parasite issue was 10,000 per acre per week in which the female proportion ranged from 57–66 per cent.

The larval population was estimated weekly. As the search for them conduced to injury of plant and larvae, as well as to obvious difficulties due to depopulation, separate plant samples were taken on each occasion by moving over an arbitrary number of plants from the random points found for egg sampling locations. The method took into consideration the relationship between high egg counts and better growth and stand as well as the undoubted influence such circumstances exert on other members of an insect community, many of which are predatory on the larvae of *H. obsoleta*.

The instar of a larva was recorded when found by measurement of the head capsule width, using transparent celluloid rules for the purpose. The division of the larval population into instars supplied information on the extent of mortality and when it was most pronounced. In actual practice, of the six larval stages of *Heliothis*, the records covered the third to sixth stages accurately, but not the first and second, as the very young larvae are too inconspicuous. For present purposes it sufficed to obtain accurate counts of the older worms for comparisons of survival under differentiated parasitism.

Irrigated Winter Crops.

Individually these are small acreages of market-garden crops generally contiguous to orange and grapefruit trees, all of which are food-plants of the bollworm.

Owing to the dispersion behaviour of *Trichogramma* and the limited area planted to a crop, it was found of little avail to experiment with the parasite in single crops. The whole of the irrigated section of crops and citrus trees on a farm was therefore treated as one experimental area, the aggregate acreage being perhaps 25 acres, but with the component portions disposed at varying intervals according to the contour of the land.

A succession of vegetable crops is planted from August to September or October, and during that period *Heliothis* moths are present in increasing abundance in some portions of these, or in the orchards, depending on the flowering condition and relative attraction of the different plant areas.

Trichogramma were released centrally in each of the more considerable blocks of every crop as soon as flowering commenced and weekly thereafter until oviposition declined. Usually there were several liberations each week to serve different sections. The rate of issue was 10,000 per acre weekly and at times this meant a total liberation of 60,000 to 100,000 parasites.

Exceptionally heavy oviposition occurs on the winter crops, particularly in the late season. These, together with weeds, represent the only food-plants in succulent growth, and bollworm is concentrated thereon. The situation appeared to be most favourable for testing the efficacy of *Trichogramma*, as a large and rapid multiplication of progeny could be expected to increase the numbers liberated over a lengthy period in the same restricted locality. Dispersion would occur, but it was hoped that a high proportion of those flighting from any one crop would enter others. In any event the net result in egg parasitism would come under review as records were taken in every crop.

Parasites were released in the following manner. Conical paper cups* containing slips of cardboard bearing parasitised eggs due for emergence were suspended with the point upwards under a portable, miniature grass roof with steeply sloping sides and ends for protection against storms. The edge of the roof was 10 to 12 inches from the soil surface. A fine hole in the tip of the cup served for exit and in order to draw emergents thereto, light was admitted only through the terminal half inch of the cone by coating the remainder with black enamel. The object in view was to delay dispersion, as previous observations had shown that the method of releasing on the wing followed in the large fields of summer crops favoured an *initial* rapid flight from the container due to excitation on exposure to full sunlight. Preliminary tests in the use of the cups showed that the outward movement from the shelters was protracted. Small groups collected from time to time on the outer side of the cup near the tip, thence crawling or flying downwards beneath the grass roof in a slow, intermittent stream.

The vegetable crops were sampled by taking 16 randomized sections of row lengths, or squares, per one-quarter-acre, according to the varied planting systems, conversion factors being used to express results on a common basis of unit area. As stated later, the parasite was entirely ineffective in citrus orchards and the method of examining them is omitted.

For the remainder, the methods and materials were essentially the same as those employed in summer work.

IV. Summer Season Experiments.

Maize.

The starting point of bollworm attack in the summer is to be found frequently in early maize. In all probability it derives from moths emerging and flying from irrigable lands that no longer bear flowering crops. Furthermore, according to the histories of infestations in the irrigated sections, the moths should represent a final, major flight from these, the principal known sources of summer bollworm. Destruction of the generation on early maize would have a most important bearing on the aftercourse of bollworm activity in cotton. To that end we have studied the control benefit resulting from releases of *Trichogramma* in maize. In the example given, the field was one of 15 acres.

The active fraction of the eggs was determined in seven of the central quarter-acre blocks. The mean percentage of active eggs over the whole period of oviposition in any block was not significantly different from any other. Some of the differences between the means of the day-to-day figures, however, were significant. Hence the active fraction was calculated on the daily counts of eggs by taking out the appropriate percentages. The data are given in Table I.

Averages of the daily means were applied in the remaining 53 blocks of the field where twice-weekly counts prevailed.

The progress of oviposition is illustrated in fig. 1. Excepting magnitude, the period and course shown in the figure are typical of oviposition on maize here.[5] Nearly three-quarters of the eggs laid on maize are deposited over 9 to 12 nights, so that, from the control point of view, the parasite must be efficacious in a limited period. It will not be out of place, therefore, to dwell here on the estimated extent of the parasite population issued and developing within the field to meet the situation.

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* The use of conical paper cups was suggested to the senior author by Mr. Wishart of the Dominion Parasite Laboratory, Belleville, Canada.

TABLE I.

Mean Daily Percentages of Active Eggs.

Dates of Oviposition	Mean	S.E.	$\frac{\text{S.E.} \times 100}{\text{M}}$
Jan. 3 ...	60·0	3·80	6·3
,, 4 ...	44·7	6·16	13·7
,, 5 ...	66·0	2·56	3·9
,, 6 ...	56·0	4·16	7·4
,, 7 ...	49·6	3·18	6·4
,, 8 ...	54·3	4·66	8·6
,, 9 ...	58·4	3·74	6·4
,, 10 ...	66·4	4·40	6·6
,, 11 ...	61·3	6·04	9·8
,, 12 ...	61·0	7·34	12·0
,, 13 ...	57·1	5·04	8·8
,, 14 ...	64·6	7·80	10·2
,, 15 ...	68·3	6·50	9·5
,, 16 ...	60·4	5·24	8·7
,, 17 ...	67·4	7·44	11·0

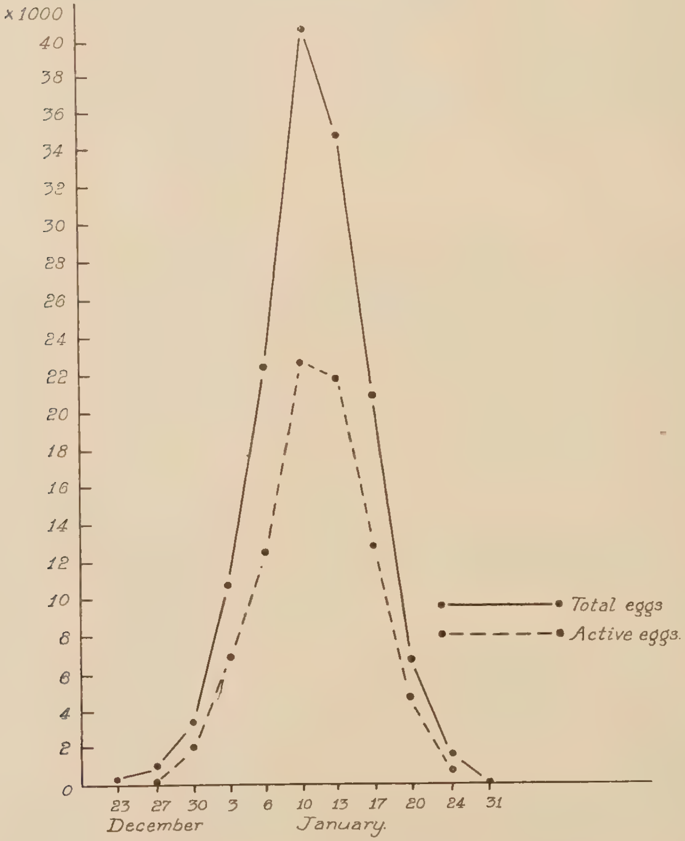

Fig. 1. Course of oviposition by *Heliothis obsoleta*; total and active eggs in maize release experiments.

Trichogramma were released first on the 28th December and thereafter at three- or four-day intervals until the 20th January. Taking the average of the female proportion to be 60 per cent., 3,000 females were issued per acre each time. These numbers, however, were not cumulative, except as provided for in the following train of events. It may be explained, firstly, that the longevity of the parasite in nature is not known ; but when confined by us in cages of cellophane and bolting silk on segments of cotton plants in the field, death supervened generally by the sixth to seventh day of adult life. The provision of food, diluted honey or the excretions at floral nectaries, prolonged life in the laboratory, and when caging *Trichogramma* on cotton plants occasion was taken to enclose advanced flower-buds at and near the stage when the nectaries of this plant function most freely. Relays of bollworm eggs placed in the cages were parasitised successively up to the fifth, and sometimes, sixth days. Now, accepting that parasitic activity by the females released in the experiment was not continued beyond a week, there would never be present more than an accumulation of two successive lots, or 6,000 of the issued females ; at the third issue members of the first would have died or become ineffective. Their progeny would, however, intervene somewhat as follows.

The developmental period of *T. lutea* is ordinarily seven to eight days under summer temperatures. Thus the earliest progeny from the first release would emerge about the 4th January. Thenceforth daily additions to the parasite numbers would be expected from emergences in the field and the totals present during the main period of oviposition might be large, depending on previous egg numbers and the degrees of parasitism. Fig. 2 illustrates an estimated multiplication of females during

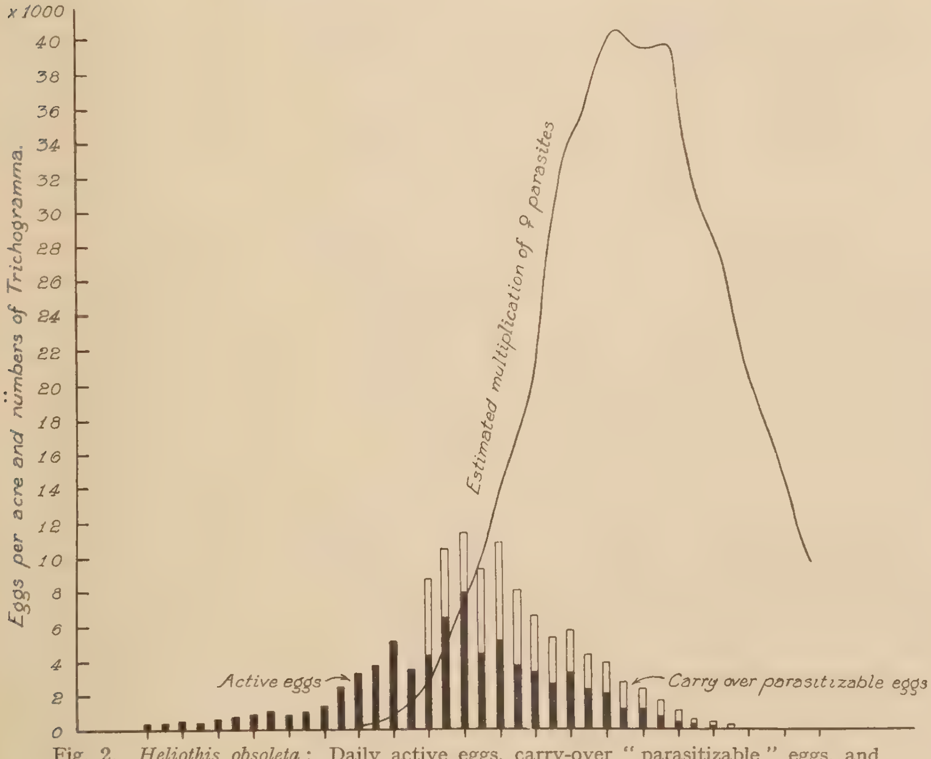

Fig. 2. *Heliothis obsoleta* : Daily active eggs, carry-over " parasitizable " eggs, and graph of additive female progeny.

the experiment. Fifty per cent. of the emergent parasites were calculated to be females (p. 224). The data were taken from daily records on parasitised eggs in four of the central blocks, giving an estimate based on one acre. In computing the figures, only eggs having parasite exit-holes were considered. The mean number of *Trichogramma* emerging from several thousands of *Heliothis* eggs collected over a long period was 2·7. The numbers of eggs with exits were therefore multiplied by 2·7.

In fig. 2 the daily egg numbers (active eggs) are charted together with the carry-over of parasitisable eggs (p. 220) from the previous 2 days. These data, with the graph of additive female progeny, are given only as an indication of the extent to which the growth of the progeny could attain within the field. Owing to dispersion factors the numbers would be transiently less, or perhaps greater. It is not improbable that, including issued numbers, the females present from the 4th to 15th January ranged from 6,400 to 20,000 per acre in *some* portions of the crop.

For comparisons under differing conditions of egg parasitism, larval numbers per block may be computed at any suitable intervals of time after egg-laying has declined and after larvae produced during the main laying period have mostly advanced beyond the second instar, when they are more readily observable. By adding larval counts taken on the 24th and 31st, representative samples of larvae in all stadia were obtained. Excluding first and second instars because of the personal error, these larval numbers were tabulated against known parasitism in the active eggs up to the 17th. Larvae from eggs deposited from the 14th to the 17th had attained the third and fourth stadia by the 31st, and were therefore counted, whereas larvae arising after the 17th were excluded as young worms.

On inspection of the data, it was not possible to determine notable differences between the larval population of the blocks by grouping or otherwise. This was the experience from other similar experiments. The information has therefore been treated by the regression of parasitism on larval survival ; the latter being expressed as a percentage of the active eggs per block.

The regression line is obtained (1) from the linear equation

$$Y = a + b\ (x - \bar{x})$$

where $a =$ a constant
and $b =$ the regression coefficient calculated from the quantity

$$\frac{\Sigma\ (x - \bar{\ })\ (y - \bar{y})}{\Sigma\ (x - \bar{x})^2}$$

wherein $x =$ the individual parasitism per block.
$\bar{x} =$ the mean of x.
$y =$ the individual, proportional parasitism per block.
$\_ =$ the mean of y.

A regression coefficient of $b = -0·088$ was found. This was significant at the 0·01 level, and the relationship may be interpreted to mean that for each rise in parasitism of 1 per cent. larval numbers were reduced by 0·088 per cent. only. The regression of x on y is plotted in fig. 3. On the whole a fairly good fit to the line was obtained, but a number of rather widely aberrant points are shown. These are referable to blocks with low egg-laying and a disproportionately high larval survival—a frequent occurrence in the authors' experience, and one probably due to reduced opportunities for cannibalism, parasites and predators. Apart from these and few other less marked instances, the observed facts agreed closely with the regression relationship. Clearly the degree of control exercised by the action of *Trichogramma* was not of practical importance. Between the lowest and highest levels of parasitism, 21·2 per cent. and 82·3 per cent., larvae in the third and sixth stadia were reduced by about 5 per cent. only.

Following a usual course, larval mortality was greatest in the first two growth stages. Later, numerous predatory and parasitic agencies would further reduce the population, added to which the more advanced *Heliothis* larvae are actively cannibalistic. It was thought that after these various factors had been given expression, a comparison between the sixth or last stage larval populations of blocks might reveal differences attributable to the intervention of the egg parasite. A regression of parasitism on sixth instar larvae was calculated, as above. The resultant coefficient was $-0{\cdot}039$ with $P < 0{\cdot}01$. Actually, therefore, values assigned to egg parasitism in the previous comparisons had dwindled through additional mortality at the later stage.

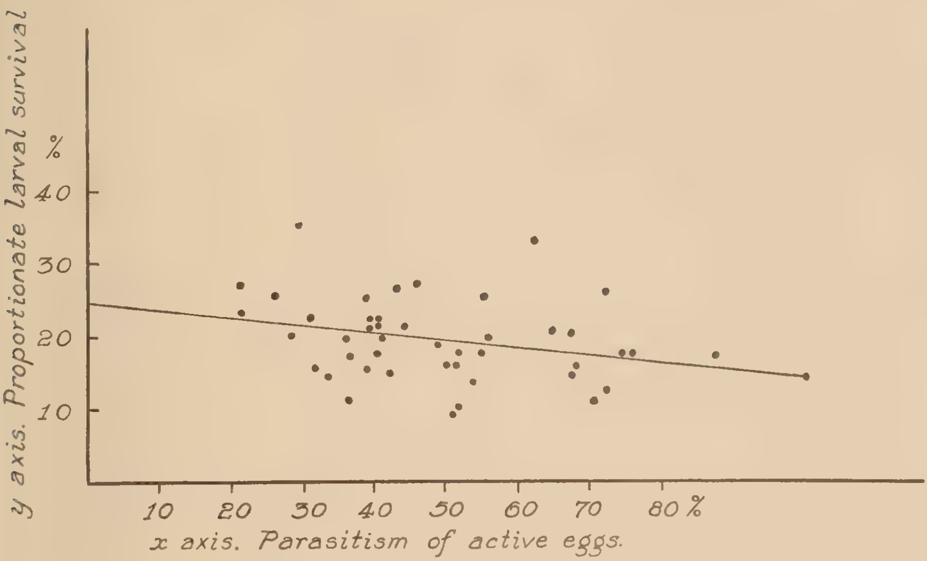

Fig. 3. Regression of parasitism on proportionate larval survival.

At this point it is of interest to consider the effect of various factors operating to offset the destruction of eggs entailed by *Trichogramma* or some other egg parasite. Suppositional examples of the combined mortality occasioned by various controlling factors in an insect population have been put forward by Dr. W. R. Thompson.[7] He distinguished between the apparent mortality (as determined by the working entomologist for individual factors) and the real mortality due to the successive impact of multiple factors on the egg to adult stages. The examples given indicated that very wide differences in apparent mortality, such as are caused through parasitism, might be unimportant in terms of real mortality.

Following Dr. Thompson's treatment, data were tabulated for several of the principal factors in bollworm mortality as obtained in the above release experiment. These are given in Table II. The figures were taken from twelve blocks where the totals of eggs and parasitism respectively were much alike. On the whole, parasitism in these blocks was greater than elsewhere in the field.

Presuming equally high percentage mortality due to the several factors, their combined effect, in the absence of egg parasitism, would be equal to 90–91 per cent. of the initial egg population. Young larvae on maize are particularly vulnerable, and it is not unwarranted to assume that with a high hatching ratio, mortality in the larval stadia would be so enhanced. In any event it is evident that egg parasitism, taken alone, exerted singularly little influence in reducing bollworm during the

TABLE II.

Stage	Factors	Estimated mortality Per cent.	Mortality as percentage of initial population (total eggs) Per cent.
Egg ...	Sterility	6·0	6·00
	Predators, climate, etc.	34·0	31·96
	Trichogramma	41·3*	25·62
Larval ...	Deaths in 1st and 2nd instars	65·2	23·75
	Parasitism 3rd to 6th instars	32·5	4·12
	Deaths between 3rd and 6th instars (cannibalism and predators)	36·0	3·07
			94·52

* The mean percentage parasitism of the active eggs was 68·8 per cent.

infestation. On the other hand, as Tucker has argued in the case of the Sugar Cane Borer, *Diatraea saccharalis*, in Barbados[8], a considerable reduction in the dimensions of the ultimate larval population, *i.e.*, those entering pupation, may be assigned to egg parasitism. According to Table II larvae amounting to 5·48 per cent. of the eggs developed to pupation size. On the above presumption, *Trichogramma* was responsible for a decrease of 39 per cent. in potential sixth instar larvae (representing 3·52 per cent. of the initial population, total eggs).

In cases where a long-standing crop experiences successive oviposition, egg parasitism of uniformly appreciable extent would probably be a valuable adjunct in reducing the scale of moth emergences. In the present instance, however, high parasitism was obtained in less than a quarter of the crop area and, being a one generation crop, it would be unsafe to rely on the problematical value of *Trichogramma* as a factor in lessening ultimate moths. It would be indefensible, economically, to breed and release parasites as a control measure on such slender grounds. If the infestation was extensive, moth production in the less heavily parasitized sections would suffice to bring about the usually damaging attack of the second generation in cotton and other crops. Apart from this it must be stated that natural parasitism by *Trichogramma lutea* in early maize frequently exceeds that obtained experimentally.

In view of the results from experiments in maize it was concluded that the parasite could not be exploited successfully in this connection.

Cotton.

Plant cotton is attractive to *Heliothis* moths for three to four months or longer. If successive quantities of eggs were laid during the attractive period, factors such as the rapid multiplication of progeny (*vide* fig. 2), reduction in larvae and hence in moths, would be given cumulative expression. Also, as a general rule, larval mortality in cotton is considerably less than it is in maize. In consequence of this, greater importance might be attached to egg parasitism.

It was known from the experiences of earlier work that moths were diverted from cotton to other neighbouring host crops, such as groundnuts, maize and beans ; all of these in their flowering periods appear to be more attractive to the egg-laying moth than cotton. The results were that oviposition on cotton, though intermittently heavy, was never sustained sufficiently long to allow opportunity for the interplay of the above factors. Frequently oviposition declined to a point where hosts for the issued parasites were extremely low.

In order to test the value of *Trichogramma* in cotton and, at the same time avoid the influence of other crops on moth activity, release experiments were conducted in ratooned cotton. This comes into abundant flower several weeks before the planted crops of the season have progressed to the fruiting stage. Ratooned cotton becomes a focal point for moths emerging with the onset of spring in irrigated lands near by. It commonly receives a heavy oviposition that is sustained over two months.

The procedure of these trials was essentially the same as that described for maize. Liberations were made twice-weekly, at the rate of 5,000 *Trichogramma* per acre throughout the duration of oviposition.

Although repeated experiments were carried out in successive seasons, a high level of parasitism was never obtained, being at the most 35 per cent. of the active egg fraction, which, so far as could be ascertained, did not lead to a measurable reduction in the third to sixth instar portions of the larval population. Higher natural parasitism than this has been recorded in cotton here ; occasionally it has reached 50 per cent., but on the whole it is considerably lower than obtains on the other food-plants of *H. obsoleta* grown with cotton.

The growth habit of the cotton bush, and the scattered manner of egg deposition thereon, suggests that *Trichogramma* is less likely to encounter a high proportion of the eggs on this plant than on others where the egg-laying sites are more contained. The analyses given in Table III of the egg distribution on cotton and maize plants supports this. A parasite moving up the stem or along an upper leaf of a maize plant readily comes into contact with a number of eggs lying closely together and may parasitise each, whereas a cotton plant may bear a large number of eggs at points well separated from each other, many of them difficult or impossible of access to the parasite. In this connection, hairiness is an important factor, particularly the density of hairs. The egg-laying sites on the cotton plant may be grouped into four classes according to the surrounding pubescence as well as the observed reactions of *Trichogramma* at representative points. These latter strongly indicate that the parasite cannot, or does not, persevere in attempts to reach approximately 17 per cent. of the eggs by reason of the impediment and probable irritation offered by the enclosing hairs. It should be noted that the cotton in question has been developed for resistance against attack by the Jassid, *Empoasca facialis*, Jac., and added hairiness has influenced selection in this regard.

TABLE III.

Classification of Egg-laying Sites of Heliothis obsoleta.

Cotton		Maize	
Position	No. of eggs	Position	No. of eggs
Leaf surfaces	536	Stalk	629
Bracts	364	Leaf surfaces	305
Leaf stems	122	Tassel florets	224
Bud and flower stems	116	Leaf undersides	77
Upper branches	109	Silks	31
Leaf undersides	86	Cobs	22
Boll stems	29		
Leaf buds	17		
Upper main stalks	13		
Growing tips	8		
Flowers	6		
Young bolls	4		
	1,410		1,288

The common indigenous race of *Trichogramma* was found to be of no measurable value when released in cotton. The investigations in cotton concluded with trials of a race introduced from Rhodesia on evidence obtained there of unusually high natural parasitism in cotton. This did not contribute results superior to the indigenous race and experimental releases were abandoned in view of their continued non-success.

V. Winter Season Experiments.

One farm, with an area of 25 acres of irrigated crops and orange groves, was utilised for the experimental releases. Two other neighbouring farms were surveyed weekly for records on natural parasitism.

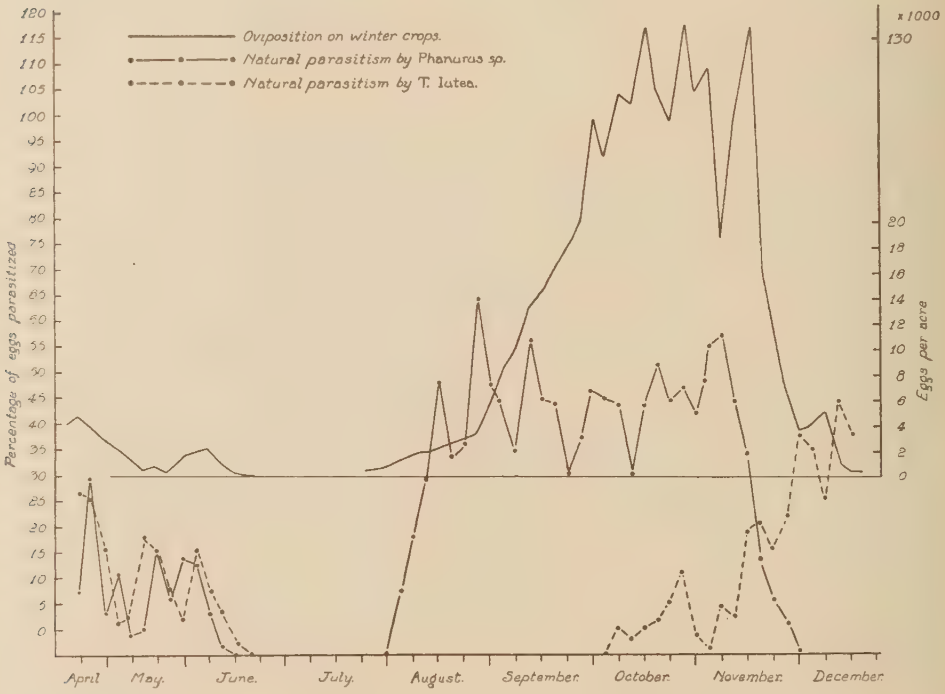

Fig. 4. *Heliothis obsoleta* : Oviposition and parasitism in winter crops.

The course of oviposition on winter crops as recorded in two non-release areas during the last two years of the work is illustrated in figs. 4 and 5. The graphs, however, do not include estimates of the egg-laying in citrus orchards. The principal varieties of oranges grown are the Washington Navel and Valencia. The occurrence of a certain amount of out-of-season blossoming is not uncommon, but as a general rule Washington Navels blossom in late August followed about a fortnight later by Valencias. Flower production in abundance endures for two weeks or so in each case, and the associated oviposition is commonly extensive and may be extremely heavy. The aggregate laying on market-garden and orchard crops at this time of the year may assume colossal proportions, and with one variety of citrus attracting the moth immediately following a decline in attraction of the other, this high laying period extends over four successive weeks.

In these experiments *Trichogramma* releases commenced coincidentally with the resumption of oviposition after the mid-winter cessation of moth activity, as shown in the diagrams. The parasites were released weekly at the rate of 5,000 females per acre during August and September, and afterwards twice-weekly until egg-laying fell off with the termination of flowering amongst the irrigated crops. The presence of a continuous, concentrated supply of host material augured well for the successful employment of the parasite.

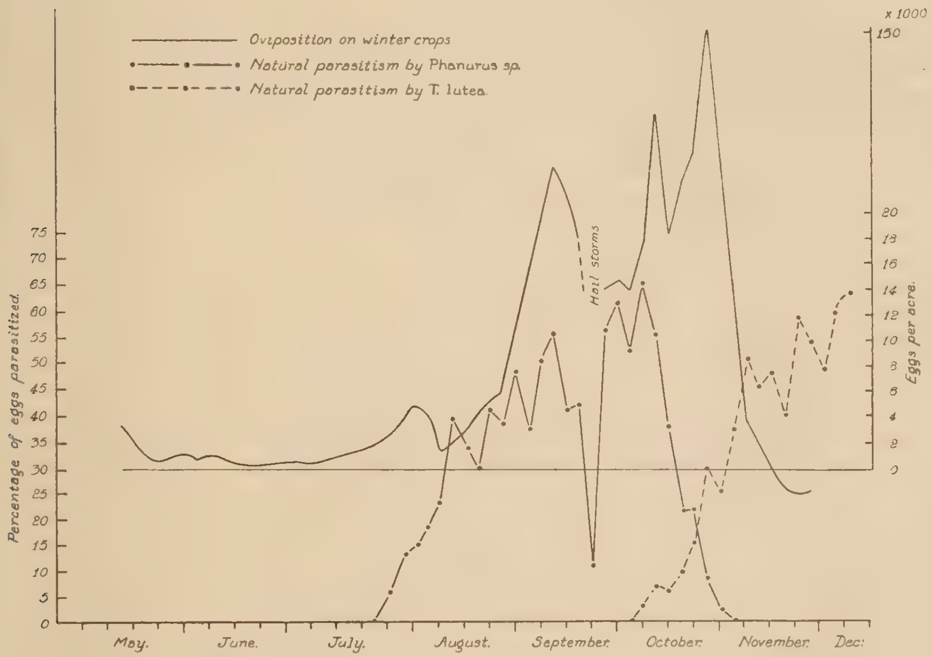

Fig. 5. *Heliothis obsoleta* : Oviposition and parasitism in winter crops.

The principal results may be summarised briefly as follows :—

Only minor degrees of parasitism resulted from the August, September, and October releases of *Trichogramma*. The present writers have not studied the temperature reactions of *T. lutea*, but it would appear from concurrent observations on the course of natural parasitism that it is inactive in the cool season. Natural parasitism for the two seasons concerned is plotted in figs. 4 and 5 from which it is seen that *Trichogramma* was not found until early October. It is noteworthy that appreciable results from the laboratory-bred material did not arise before the recrudescence of natural parasitism.

In both of the examples given in figs. 4 and 5, egg parasitism due to *Phanurus ullyetti*, Nixon (Scelionidae) is illustrated. The presence of *Phanurus* in winter crop areas was noted when these investigations began and, with the introduction of intensive methods of recording, it was found to be very active in the cool season, as evidenced by the graphs. Towards the close of winter crops it became scarce and it is rarely found in eggs collected from summer crops. Actually within the period when *Trichogramma* is inactive, *Phanurus* accomplishes much that was hoped for from the former in the destruction of bollworm eggs on market-garden crops, although neither insect parasitises eggs on citrus to any extent.

In nature the effect of *Trichogramma* is to engage in egg parasitism about the time when *Phanurus* ceases to be an important factor in that connection. The question arises whether *Phanurus* would persist, for a time at least, in the absence of *Trichogramma*. The developmental period of the former is usually two weeks and only one adult emerges per egg, whereas *Trichogramma* commonly develops in a week, and two to three or more adults emerge from each *Heliothis* egg. *Trichogramma*, therefore, may practically eliminate *Phanurus* in this host in the spring and summer months. According to our laboratory records, however, it is probable that temperature is likewise an important factor.

Attempts to utilise *Trichogramma* in winter crops were directed, perforce, to increasing parasitism in the October and November egg populations. In general the results were not encouraging, although in individual crops, particularly members of the Solanaceae, definite gains were established. These crops, however, comprise a relatively small proportion of the whole, and the situation, as at present known, would not warrant the introduction of the laboratory-bred *Trichogramma*.

Further investigations on winter parasitism are required.

VI. Summary.

Some of the problems involved in the estimation of parasitism in populations of *Heliothis* eggs are discussed :—

(*a*) Effective parasitism of the " active fraction " of eggs as laid *in situ* is defined.

(*b*) The habits of the egg-laying moth in point of the duration of oviposition on individual crops and diversion of moth activity from one host to another are discussed in relation to releases of *Trichogramma lutea*. Data are given on the distribution of bollworm eggs in a crop and associated factors.

(*c*) Investigations on the dispersion of liberated parasites are described. Dispersion was found to be rapid and widespread ; concerted activity by large numbers in given areas did not apply.

Investigations in rain-grown crops are described and results are quoted from a typical experiment in maize, wherein the percentages of parasitism recorded in a large number of equal sections of the crop are regressed on proportionate larval survival. Although the egg parasitism ranged from 21·2 per cent. to 82·3 per cent., differences in larval populations were inappreciable. An explanation for this is offered in an analysis of the effect of various mortality factors.

The parasite was relatively ineffective in cotton crops. The low degrees of parasitism found are assigned to the growth-habit of the plant, the scattered manner of egg deposition thereon and the impediment offered to the insect by the dense hair processes of the plant at many sites where eggs are commonly placed.

Investigations on irrigated (cool season) market-garden crops and citrus orchards are described. These form the principal breeding sources of summer bollworm. Oviposition is extensive and sustained for three to four months on these crops, thereby affording opportunity for continuous parasite activity and the cumulative participation of progeny bred in the field. In nature *Trichogramma lutea* does not, however, appear until the latter end of the egg-laying by *Heliothis* and the authors were unable to establish laboratory-bred representatives at an earlier period.

Another egg parasite, *Phanurus ullyetti*, is prevalent before *Trichogramma* appears and accomplishes much that was hoped for from the attempted earlier introduction of *Trichogramma*. In effect, the latter, as seen from diagrams furnished with the paper, becomes substituted for *Phanurus* toward the close of the winter season. It is probable that temperature is a determining factor in the biology of both parasites, although other causes for the observed relations are suggested.

Further investigations are needed on the subject of exploiting *T. lutea* in the cool season.

VII. Acknowledgments.

The authors wish to thank Dr. F. W. Pettey for opportunities given them to inspect his equipment used in the breeding of *Trichogramma* at Elsenburg, South Africa, and for placing at their disposal diagrams and information procured by him in California.

We are greatly indebted to Mr. W. G. Cochrane, of the Statistical Department, Rothamsted Experimental Station, for help in the analysis of data, and to Dr. W. R. Thompson, Farnham House Laboratory, for reading the manuscript and advising on the presentation of the subject matter.

References.

[1] Fisher, R. A. (1930). Statistical Methods for Research Workers. p. 114, Third Edition.

[2] Flanders, S. E. (1927). Biological Control of the Codling Moth (*Carpocapsa pomonella*).—J. Econ. Ent., **20,** p. 644.

——. (1930). Mass production of egg parasites of the Genus *Trichogramma*.—Hilgardia, **4,** pp. 465–501.

[3] Harland, S. C. & Atteck, O. M. (1930). Breeding experiments with biological races of *Trichogramma minutum* in the West Indies.—Z. indukt. Abstamm. u. VererbLehre, **64,** pp. 54–76.

[4] Parsons, F. S. (1930–31). Reports from Exp. Stations of Empire Cotton Growing Corporation.—p. 16.

[5] —— & Ullyett, G. C. (1934). Investigations on the control of the American and Red Bollworms in South Africa.—Bull. Ent. Res., **25,** pp. 349–381.

[6] Peterson, A. (1930). A biological study of *Trichogramma minutum* Riley, as an egg parasite of the Oriental Fruit Moth.—Tech. Bull. U.S. Dept. Agric., **215.**

[7] Thompson, W. R. (1928). A contribution to the study of biological control and parasite introduction in Continental areas.—Parasitology, **20.**

[8] Tucker, R. W. E. (1933). A contribution towards the solution of the problem of *Diatraea saccharalis* in Cane through a mathematical evaluation of the real mortality of *D. saccharalis* due to egg parasites, natural mortality, larval parasitism and other factors.—Agric. J., **3,** no. 1, Dept. Sci. and Agric, Barbados, Oct. 1933, pp. 59–79.

THE FOOD-CYCLE OF *DYSDERCUS FASCIATUS* IN ACACIA SAVANNAH IN NORTHERN RHODESIA.

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Introduction.

Within the last 25 years various unsuccessful attempts have been made to introduce cotton as a commercial crop in Northern Rhodesia. These efforts have been directed largely towards the establishment of the crop within the zone of European settlement, which consists mainly of comparatively small areas of Acacia savannah within a short distance of the railway line. The causes which led to the abandonment of the earlier trials are somewhat obscure, but the culminating failures of the 1924–25 and 1925–26 seasons were primarily due to damage caused by Jassids (*Empoasca facialis*). The introduction of Jassid-resistant strains failed to afford the expected solution of the problem, since, owing to heavy losses of crop due to American bollworm (*Heliothis obsoleta*) and to internal bollrots, the cultivation even of resistant strains proved a hazardous undertaking.

The two chief vectors of internal bollrot within the Acacia savannah of Northern Rhodesia are *Dysdercus fasciatus*, Sign., and *D. superstitiosus*, F. In addition *D. intermedius*, Dist., and a Pentatomid bug, *Callidea dregei*, Germ., play a minor part in the transmission of bollrots. The amount of damage caused by stainers varies from season to season but is generally severe, since the insects are usually present in the cotton-field from the time the first flowers open until the crop has been reaped and the plants burned. Endeavours to obtain an actual numerical expression for the damage caused by stainers have been made in each season, but the figures are of small value unless accompanied by detailed explanations. Digests of the data together with the necessary explanations will be found in periodic reports submitted to the Empire Cotton Growing Corporation[1] and need not be repeated here.

Studies of the stainer problem have now been in progress over a period of six years. The work at first consisted mainly of investigations into the possibility of controlling the pest by means of handpicking and seed traps, but such methods proved of little value and attention has since been directed to a study of the relationship of the stainers to their wild hosts. Observations on the host-plants of the stainer were made under unusually favourable conditions as the only cotton in the neighbourhood consisted of comparatively small plots under our control. Consequently the complicating factors introduced by the presence of ratooned and standover cotton were eliminated.

The information with regard to *D. fasciatus* and its hosts within the Acacia savannah is fairly complete, and the purpose of this paper is to summarize and co-ordinate these data. The food-cycle of *D. superstitiosus* would appear to be somewhat more complex. Information with regard to the cycle is complete for the major portion of the year, but the manner in which this species survives the exceedingly arid period from mid-September to the end of October requires further investigation. The food preferences of these two species differ greatly. Breeding of *D. fasciatus* is confined to arborescent and perennial plants, while *D. superstitiosus* appears to depend on a succession of annual *Hibisceae* for its major breeding. In the case of *D. intermedius* large populations have been found only on *Sterculia* sp.* and the relative unimportance of this stainer would appear to be due to the fact that the tree does not occur within the Acacia savannah.

Vegetation and Climate of the Mazabuka Area.

The work now summarized has been carried out at the Mazabuka Experimental Station, which is situated in thorn country of the savannah type wherein the predominant tree is *Acacia woodii*, Burtt Davy. The term " Acacia savannah," as we have used it, applies only to this type of country. Closely adjoining the station are the treeless alluvial grasslands of the Kafue flats. Much of the grassland is inundated during the later rains and the early portion of the dry season, while certain parts remain perennially moist.

The mean annual rainfall of the area is in the neighbourhood of 30 inches, the wet season extending from October or November to March or April, but great variation occurs both in the distribution of the rains and in the annual total. After the cessation of the rains humidity declines. The months of lowest temperature are May, June and July, when slight frosts are occasionally experienced. Temperatures increase as the sun approaches the overhead position in September and rise to a maximum in October, but humidity continues to decline and the night temperatures remain low. The figures given in Table I illustrate the seasonal range of climatic conditions experienced at Mazabuka. The saturation deficit figures are based on wet and dry bulb readings taken at 8 a.m. G.M.T.

TABLE I.

	1933				1934			
	Mean monthly temperature		Sat. def.	Rainfall inches	Mean monthly temperature		Sat. def.	Rainfall inches
	Max.	Min.			Max.	Min.		
Jan.	76·6	74·7	2·8	7·62	81·3	64·5	4·0	4·18
Feb.	81·3	62·8	4·0	6·45	80·1	64·5	2·1	6·34
Mar.	84·2	61·9	7·2	0·09	81·3	63·5	3·8	3·16
Apr.	83·3	59·0	8·1	—	83·5	60·3	6·1	0·66
May	79·9	52·2	8·9	—	82·8	60·3	8·7	—
June	78·0	52·1	7·0	—	76·1	54·7	6·1	—
July	76·9	52·3	7·8	—	72·9	53·7	7·4	—
Aug.	80·2	54·1	10·3	—	81·6	58·5	11·7	—
Sept.	84·8	59·9	13·8	—	85·6	61·4	13·0	—
Oct.	93·4	66·7	13·5	0·03	87·3	65·9	16·7	1·12
Nov.	86·7	66·1	8·7	4·09	83·4	66·5	8·5	3·80
Dec.	80·0	64·2	4·9	6·63	79·5	65·1	3·8	8·65

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* Two species of *Sterculia* are known in Northern Rhodesia. One, *S. quinqueloba*, K. Schum., has not been found to carry *D. intermedius*. The other species, to which we refer in the text, was believed to be *S. triphaca*, R. Br., but is now considered to be a distinct species.

Methods of Recording Stainer Population in Cotton.

Stainer counts on cotton were commenced in 1929 and continued in each subsequent season, but the methods employed have varied considerably. In every case all stainers found on the sample were removed and species and sex ratio counts were made in the laboratory. During the first two seasons weekly pickings were carried out over four rows of cotton comprising a quarter of an acre in a field of two acres. The sample rows were changed each week in order to interfere as little as possible with the population. In 1931–32 a similar method was employed, but the sample area was reduced to one-tenth of an acre in a field of five acres. During these three seasons experiments were being carried out on control of stainers by means of seed traps and hand-picking. The distribution counts were checked against the figures obtained from these experiments and were found to be in close agreement. This simple sampling method, however, is open to many objections and cannot be expected to give more than an indication of the major changes of population in the field.

For this reason, and in view of the desire for a uniform system to be used by workers on similar problems, a new method was introduced based on that devised by Clapham[2] and its use has been fully described by Pearson[3]. The authors employed this method in 1933 but the results were vitiated owing to defoliation of the crop by locusts. The figures from which the population diagram of 1933 has been compiled were obtained from a trial of strains laid out on the randomised block system. Ten samples of four plants were taken at random in each of eighteen plots, the total sample approximating to one-tenth of an acre.

In 1934 another method was employed which, it was hoped, would obviate certain disadvantages of the Clapham method. In order to ensure sampling over the whole area the field was divided into 80 plots of equal size and within each plot a random sample consisting of a double-row length was taken. The area sampled was ten acres and the total sample amounted to ten per cent. of one acre. This method was again used in 1935.

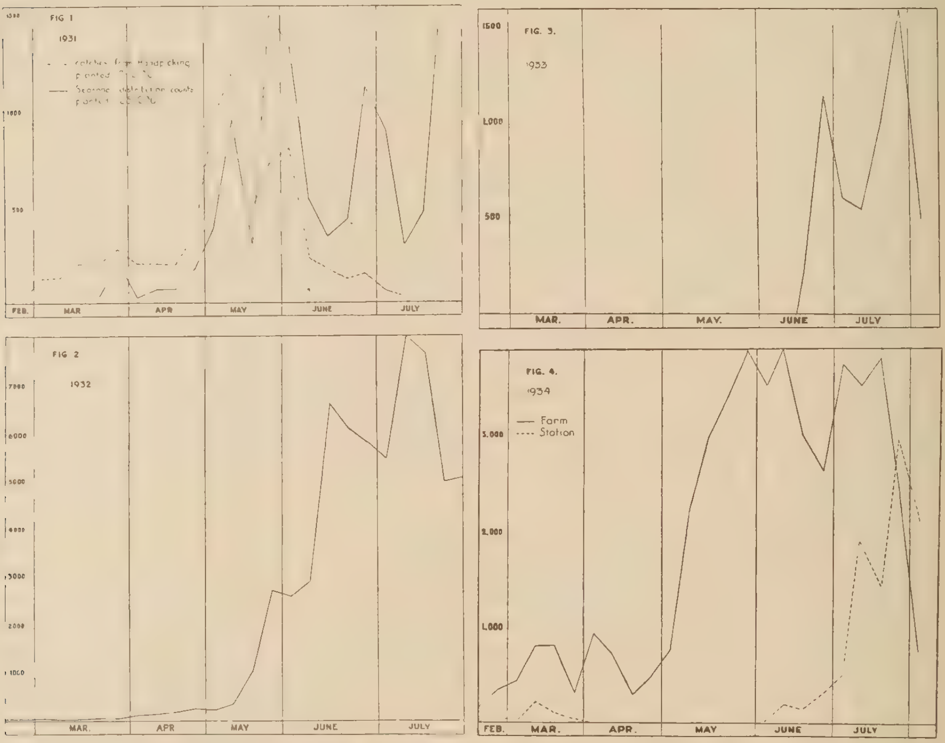
Seasonal Distribution of D. fasciatus on Cotton.

The results obtained from the seasonal distribution counts for the years 1931 to 1934 are illustrated graphically in figs. 1 to 4.

It will be seen that there is considerable variation from year to year in the date of first appearance of adults and correspondingly in the number of generations bred on cotton. In addition to adults, nymphs of the fourth and fifth instars were collected and the figures for their distribution were used to distinguish between population maxima due to influx and to maturation of adults in the field. The sex ratio counts were also of assistance in differentiating between influx and breeding peaks, because maturation of a generation is always accompanied by a preponderance of males, due to the shorter development period of this sex.

Counts were generally discontinued at the end of July, as by that time the crop has been picked. In one year standover cotton was allowed to remain until November and the counts showed that *D. fasciatus* will continue to breed in some numbers during the period August–November.

1931. In this year the counts were made on a late planted bulk of cotton and this delayed planting affected the distribution considerably. Two graphs have therefore been plotted, one consisting of figures obtained from daily hand-picking over an acre (reduced to weekly means), while the other shows the figures obtained from the ordinary distribution counts. The hand-picking was carried out on cotton planted eighteen days earlier than that used for the seasonal distribution counts. Stainers first appeared in the early cotton at the beginning of March and the influx continued during that month and April. In the latter part of April adults of the F. 1 generation were becoming abundant in the field and the maturation of the new generation reached a peak at the middle of May. A similar peak of adults, which however cannot be attributed to breeding in the field, occurred in the late-planted cotton and would seem to have been due to a movement of F. 1 adults from the earlier plantings. Three further peaks occurring at intervals of four to five weeks are clearly defined and can be attributed mainly to the maturation of successive generations. The relatively small densities of the F. 2 and F. 3 generations in the case of the hand-picked cotton are presumably due to continuous removal of adults and nymphs from the field.



Figs. 1–4. Seasonal distribution of *Dysdercus fasciatus* on cotton.

1932. The main influx was somewhat later than in the previous year. Occasional adults were taken in February and March, but during these months there was apparently no breeding in the field. The main influx occurred during April and early May. It is clear from the nymphal counts that the population during the earlier part of May was composed largely of adults of the influx generation, while during the latter part of the month it consisted almost entirely of newly matured F. 1 adults. The peak representing maximum emergence of the F. 1 adults occurred in mid-June and was followed some four weeks later by a still higher peak representing maximum maturation of a second generation.

1933. In this season the first appearance of *D. fasciatus* in the field was remarkably late, no adults of the species being recorded until 21st June. A large influx of adults took place during the latter part of June which was followed by maximum emergence of an F. 1 generation towards the end of July.

1934. Observations during this season were made both on the station and on a neighbouring farm and the figures obtained from the two counts are reproduced.

On the farm influx commenced in February and took place in two waves, the peaks of which occur in March and April respectively. This was followed by rapid breeding, giving rise to a succession of intermixed generations. On the station the influx took place at about the same time. This was not followed by breeding and the adults rapidly disappeared from the field. The disappearance was undoubtedly due to the complete destruction of the early and middle crop by American bollworm. The plants recovered to some extent from this attack and set a small crop in late May. A heavy influx of *D. fasciatus* then began, and large numbers were flighting into the cotton during June, the infestation being very similar to that of the previous year.

The Hosts of Dysdercus faciatus.

The following list of host-plants comprises those observed in the Acacia savannah only. They have been grouped according to their observed relative importance in the life-cycle. A major host may be defined as one on which the species will live and breed in large numbers so long as a food supply of any kind is available and the condition of the host is favourable to continued breeding. A subsidiary host may be regarded as one on which the species will live and breed but will leave while an apparently satisfactory food supply remains and while the condition of the host still favours breeding. A minor host is one on which adults specimens have been observed in fairly large numbers over some period and in which they have been seen to feed.

(*a*) Major hosts :
Thespesia rogersii, Moore } Arborescent
Andansonia digitata, L. } species.

(*b*) Subsidiary hosts :
Hibiscus dongolensis, Del.—Shrubby perennial.

(*c*) Minor hosts :
Hibiscus asper, Hook. f.—Annual.
H. cannabinus, L.—Annual.*

Thespesia rogersii, Moore.

This species is abundant throughout the Acacia savannah and numerous trees occur in the neighbourhood of the cotton plots on the station.

The course of flowering is illustrated by means of the figure below (fig. 5), which is based on weekly counts of flowers on 19 sample plants. Vigorous and general flowering begins after the first rains in November and the peak is reached in January. Though there is a well defined peak of maximum flowering, individual plants may flower sporadically at almost any time of the year. The quantity of fruit set and carried on the trees is to a very large extent determined by the prevalence or otherwise of the larvae of a certain Cossid moth which destroys the buds, flowers and young fruits. Thus in the 1932–33 season the Cossid larvae appeared in such small numbers that practically the whole of the early crop was set and carried to maturity. In the other years for which records are available the crop was virtually destroyed and only a few of the later-flowering trees succeeded in maturing fruit. In 1933, when the early crop was retained, fruit-opening commenced early in February, while in the other years when only the late crop survived the attack, the first fruits began to open in March or April. The very early opening in 1933 may have been influenced to some extent by the early cessation of the rains in that year. The fruits rarely open wide enough to permit of the seed being shed and some may be retained on the tree for a period of at least two years. The seeds are surrounded by a sweet-tasting mucilage favoured by the native and much fruit is picked, usually in August. The carpel wall of the developing fruit is exceedingly tough and fibrous and is from 4 to 5 mm. thick. The adult *Dysdercus* is capable of penetrating this wall, but the nymph has never been observed to feed on unopened fruit.

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* These two species presented considerable difficulties in taxonomy. Both were at first regarded as forms of *H. cannabinus* and were so alluded to in reports[1]. Subsequently both were provisionally returned by the Royal Botanic Gardens, Kew, as forms of *H. asper* and were so described in a contribution to the Second Conference on Cotton Growing Problems[4]. On provision of further material it was found possible at Kew to differentiate the two species in the Mazabuka plants. Field observations suggest that the reason for the taxonomic difficulty is the presence of a hybrid population.

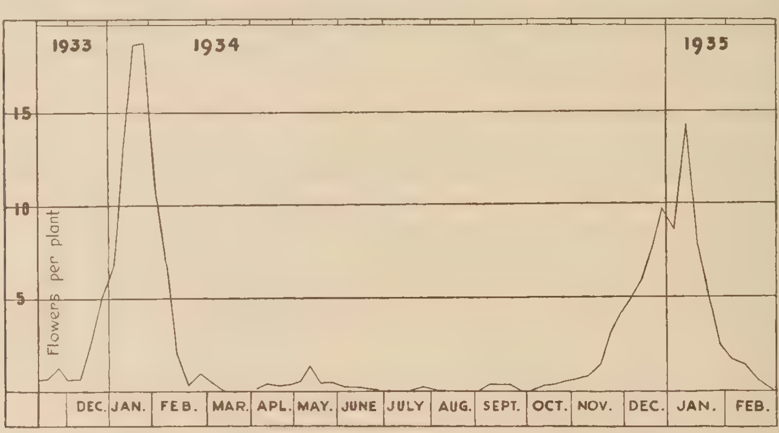


Fig. 5. Flowering of *Thespesia rogersii*.

The tree under the conditions to which it is subject during the long dry season is more or less deciduous. Leaf-shedding generally begins in April, and during June and July, the months of lowest temperatures, most trees are almost or completely bare. Defoliation is furthered by the grass fires which sweep the countryside during this latter part of the dry season. New foliage appears when the temperature rises in late August or September, and in November most trees are again in full leaf. A few favourably situated trees protected from grass fires carry the greater part of their foliage throughout the year.

Andansonia digitata, L.

There are five baobab trees in the neighbourhood of the station cotton plots but fallen fruits are immediately collected by natives. Consequently, during the period covered by our records the trees have never provided a food supply for a stainer population. Throughout the Acacia savannah baobab is found only as very occasional isolated trees and is of little importance as a host. In a few areas considerable populations of the tree occur on rocky hillsides, and in such situations fallen fruit accumulates and provides a large food supply whereon *D. fasciatus* breeds in great numbers throughout the year.

Hibiscus dongolensis, Del.

This plant is of fairly common occurrence in the Acacia savannah locally. Vigorous flowering commences in November and rises to a maximum in January, but falls off slowly during March and April to a low level. Occasional flowers are produced throughout most of the year. The leaves tend to shed during the drier and colder periods and unfavourably situated plants lose much of their foliage. The plants carry fruit over the whole year but apparently serve as hosts only during the earlier months.

Hibiscus asper, Hook. f., and *H. cannabinus*, L.

These species are included in the food sequence only because adults have been observed in considerable numbers on them during March and April when active flighting from *Thespesia* was in progress. The adults have been seen to feed on the developing fruits but no nymphs of *D. fasciatus* have been recorded on the plants.

Methods of Recording on the Wild Host-Plants.

Recording of stainer populations on wild host-plants presents considerable difficulty. The stainers cannot be removed from the plants, and when very large numbers of individuals are present on a sample accurate counting is impossible. Finally the following method, which is suited to the capacity of the native recorders employed, was adopted. Populations under 50 could be counted with reasonable accuracy. Symbols were used to indicate population numbers lying between 50 and 100, 100 and 500, 500 and 1,000, and in excess of 1,000. Figures which clearly approached more nearly to the upper or lower limits of the groups were distinguished respectively by plus and minus signs. Information regarding flowering, fruiting and general condition of the hosts was also obtained.

Records for *Thespesia rogersii* were at first made on as many trees as possible, the recorders traversing a large area and estimating the population on all the trees encountered, while at the same time searching for other hosts. Such traverses were made at weekly or bi-weekly intervals as other work permitted. This method, while it has many advantages, necessitated the employment of a large recording staff and also entailed much supervisory work. For these reasons it was finally abandoned, and in November 1933 nineteen trees or small tree groups (the positions of which in relation to the cotton plots are shown in fig. 6) were adopted as fixed samples and population counts were made at weekly intervals on these trees by a single observer.

In January 1934 continuous recording on *Hibiscus dongolensis* was commenced. The sample used consisted of the only four plants known to lie within three miles of the cotton plots and the population was estimated in the same way as that on *Thespesia.*

Graphs have been constructed to illustrate the population variations recorded (figs. 7, 8, 9 and 10) and in constructing these figures appropriate numbers have been substituted for the symbols indicating large populations. A logarithmic scale has been used on account of the large range of values encountered and in order to show clearly the fluctuations of the smaller populations.

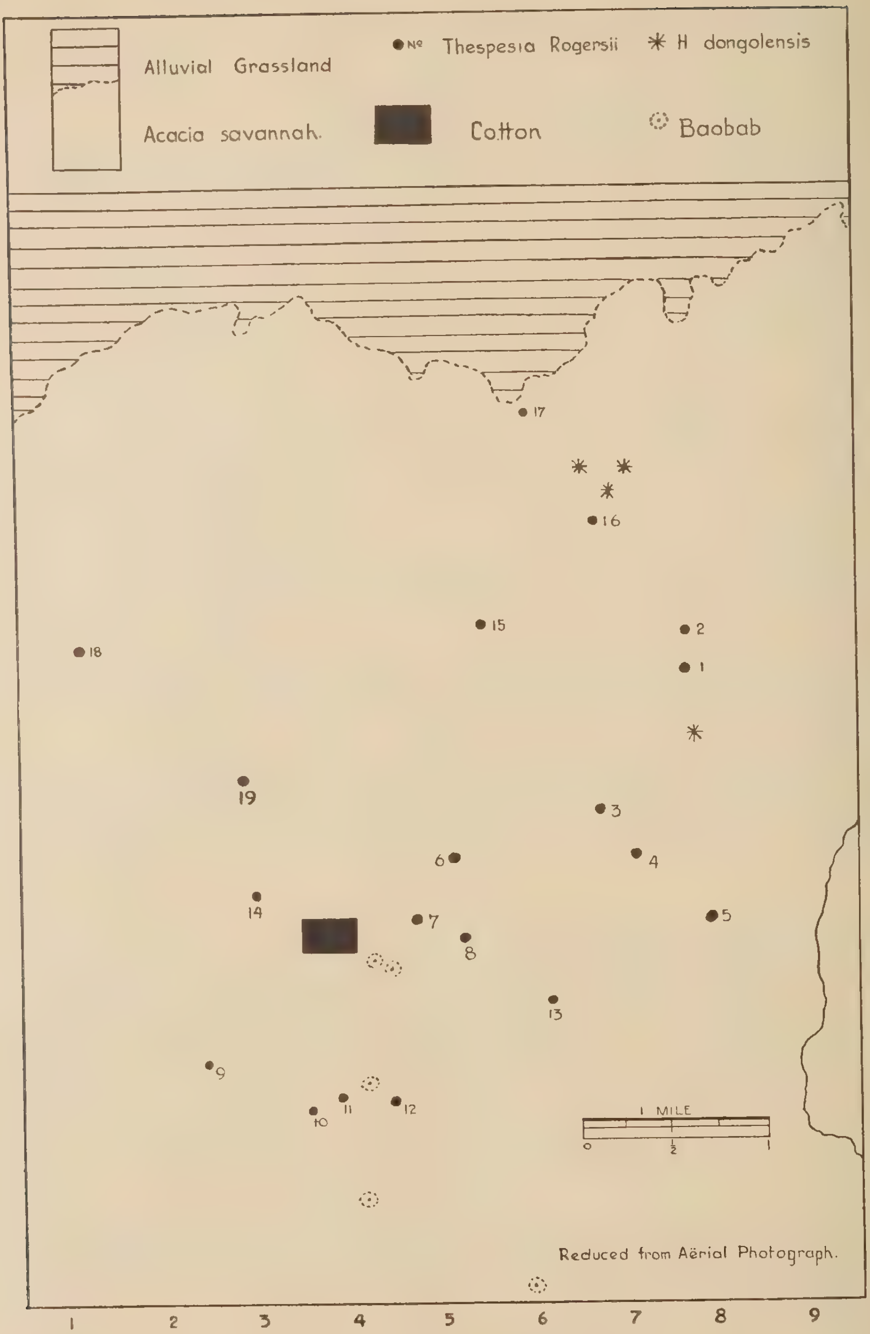
The Host Sequence of Dysdercus fasciatus.

The population figures of *D. fasciatus* on *Thespesia rogersii* obtained by the extensive recording method are shown graphically as monthly means of stainers per tree (fig. 7). The major changes in population are clearly defined and are correlated with varying conditions of the host-plants. These changes may be defined as follows :—

Defoliation Decrease.—From June onwards there is a general and rapid decrease in population which is associated with leaf-fall, loss of crop, and damage by grass-fires. Many trees lose their populations entirely and breeding is finally restricted to well-shaded trees carrying fruit. The shade factor is one of considerable importance and stainers leave defoliated trees even though they are carrying an ample food supply.

Leafing Increase.—By the middle of November most of the trees are in full foliage. Population spreads and breeding takes place on such trees as are carrying ripe fruit. This results in a rise in the general population, which rise is, however, limited by the available supplies of old fruit.

Crop Shedding Decline.—During the earlier months of the year the old fruit rots and sheds following the advent of the rains, while in some seasons (probably most) the early crop is destroyed by the larvae of the Cossid moth to which we have referred. The failure of the old fruit causes a decline in population if the early crop is lost.


Alluvial Grassland
Acacia savannah.
● Nº Thespesia Rogersii
Cotton
✳ H dongolensis
Baobab
17
16
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19
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Fig. 6. Distribution of stainer hosts used for recording.

New Crop Increase.—The crop shedding decline is checked by the opening of the new fruits. Rapid breeding follows this opening and a rise in adult population follows reaching a peak in June.

The diagram representing variations of *Dysdercus* population on *Thespesia*, from the commencement of observations in September 1931 to December 1932, follows the " normal " course and the major fluctuations are clearly defined. By January 1932 the leafing increase had reached its maximum and stainers began flighting from the trees. This movement continued during February and March and reached a maximum in early May. In March the young fruits began to open and the new crop increase of adult population followed. Flighting from the trees again began in June as the factors which bring about the defoliation decrease came into play. The numbers of stainers on the trees reached a minimum early in November 1932 when the leafing increase again began. It has been pointed out that in 1933 a very large and early crop was carried on *Thespesia*. Consequently the rise in population which began at the end of 1932 was not checked. Before a maximum population was bred upon the old fruits, the new crop was opening and continuous and increasing food supply was provided. There is therefore no sharp drop in the distribution curve to correspond with that of the previous year. Most trees set a heavy crop of fruit and by June were carrying vast numbers of stainers. Thereafter the population decreased steadily until November, but the carry-over was very much greater than that of the preceding season.

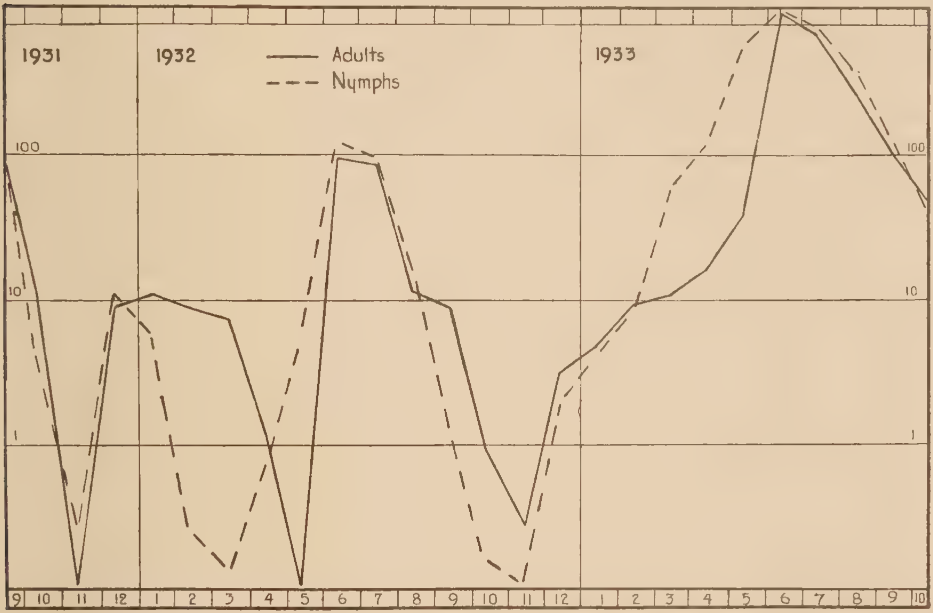
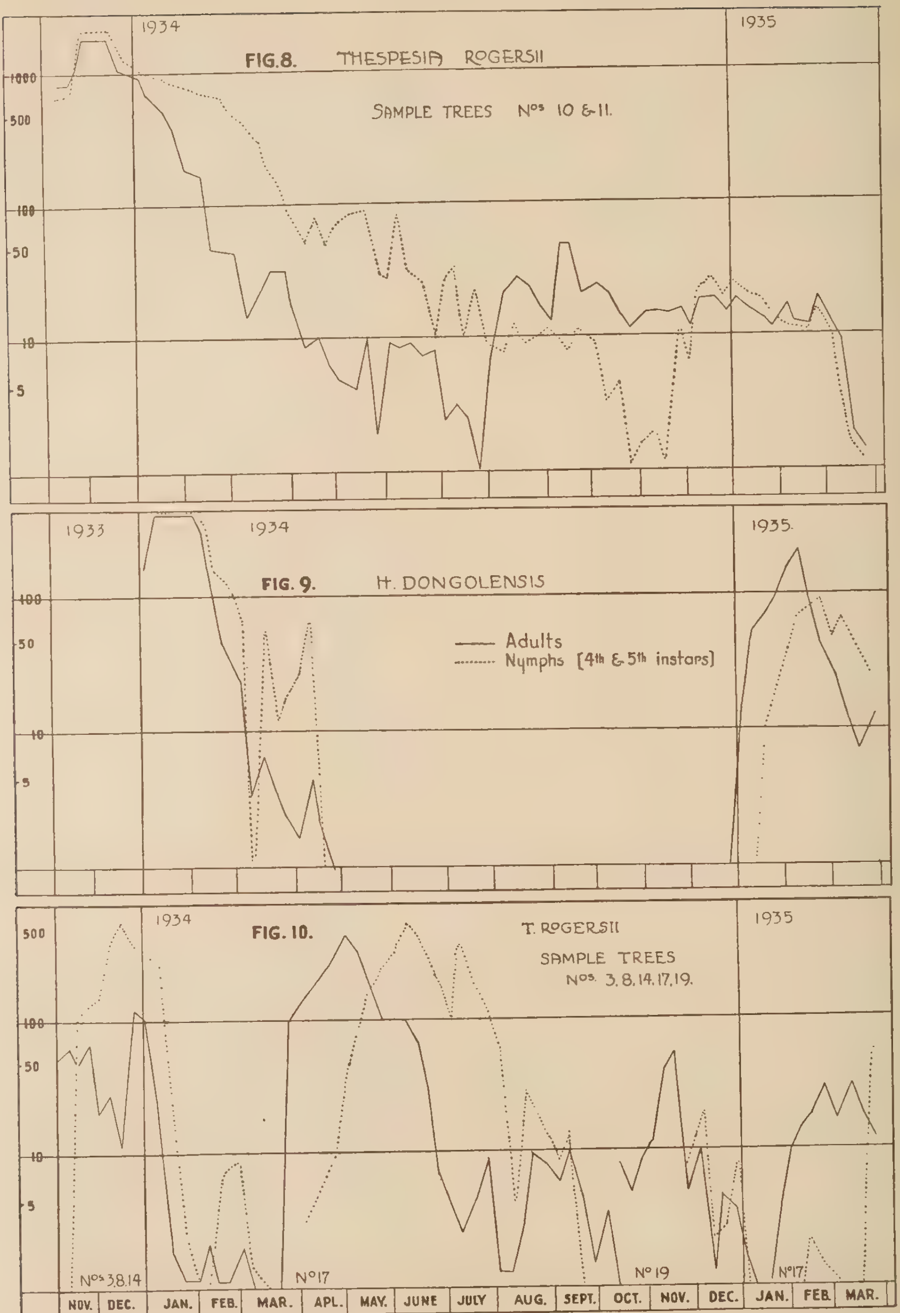


Fig. 7. Seasonal variation of the population of *Dysdercus fasciatus* on *Thespesia rogersii*.

The fluctuations of population on *Thespesia* and *Hibiscus dongolensis* during 1934–35 may be followed in greater detail as individual records were kept for 19 sample trees (figs. 8, 9 and 10). In October 1933 a stainer population remained on two only of the sample trees (Nos. 10 and 11, fig. 6). These trees were then carrying exceedingly large numbers of open fruit of the 1932–33 crop ; they occupy a situation protected from grass-fires and were well shaded, partly by retention of some of the



Figs. 8–10. Seasonal variation of the population of *D. fasciatus* on *Thespesia rogersii* and *Hibiscus dongolensis*.

foliage and partly by tall overshadowing Acacia trees. Three trees (Nos. 3, 8 and 14) had also retained a small amount of crop but were unshaded and almost or entirely devoid of leaves. In the case of the remaining sample trees the crop had been picked or had shed. In November, when new foliage was well developed, adults of *D. fasciatus* appeared on Nos. 3, 8 and 14 and breeding took place on them, the adult population so developed reaching a maximum at the end of December. The populations on Nos. 10 and 11 also increased to a maximum in December, when in the case of all the trees mentioned thick clusters of nymphs and adults could be found feeding on old fruit. In January a rapid decrease of population was recorded on each tree and this can be attributed directly to the failing food supply as the old fruit shed and rotted.

At this point *H. dongolensis*, which was now carrying a large crop of young and open fruit, acquired a population. Adults appeared on the plants in large numbers in January and active breeding took place.

The greater part of the crop set by *Thespesia* in November and December 1933 was destroyed by the Cossid moth larvae and only trees Nos. 15, 16, 17 and 19 retained any young fruit. This began to open at the end of March. The tree groups Nos. 16 and 17 flowered considerably later than the other trees, the peak occurring in February. This resulted in a heavy crop, much of which, particularly in the case of 17, survived the attack of the Cossid larvae. These two groups are situated near the site of an old native village and have been cut back at some point in their history, but have now produced a dense shrubby type of growth from stool. Similar groups occur commonly in the bush bordering the alluvial grassland and all are characterised by vigorous vegetative growth and abundant fruiting. Apparently the whole of the new crop increase of 1934 resulted from breeding on this type of plant. Immediately the young fruits were on the point of opening a large population of adults appeared on No. 17. Observations showed that some part of the population was acquired as the result of a direct flight movement of young adults from the closely adjacent samples of *H. dongolensis*. This very marked movement is difficult to explain except on the assumption that at the time the fruit is opening, *Thespesia rogersii* is strongly attractive to *D. fasciatus* and that this attraction is appreciable over some distance. When stainers disappeared entirely from *H. dongolensis* at the end of April, the plants were still in a vigorous condition, flowering freely and carrying large quantities of fruit in all stages. It is curious, however, that no migration to the more closely adjacent *Thespesia* sample No. 16 was recorded, although fruit was opening on this tree group at the same time. One explanation which offers itself is that No. 17 is much more favourably situated than No. 16, and while at the time of the migration the former was in vigorous condition the latter was already showing signs of water shortage and the foliage had commenced to wither and shed. No. 17, presumably owing to its situation in the seepage zone bordering the Kafue flats, carried a considerable amount of foliage until October and maintained a stainer population over this period. A combination of bush-fires and locust swarms resulted in the defoliation of the sample early in October and stainers disappeared from the plants. Coincident with the movement from No. 17, adults appeared on *Thespesia* No. 19 on which, although it was carrying a considerable crop of ripe fruit and much foliage (due again to a copious underground water supply), not a single stainer had previously been observed. The development of a population on this tree was rapidly checked as a result of defoliation and loss of fruit caused by locusts ; early in January 1935 no fruit remained on the tree and stainers disappeared from it completely. Adults reappeared on No. 17 about the middle of January 1935, but breeding did not commence until the beginning of February. The food supply at that time consisted of remnants of the previous year's crop as the new fruit did not begin to open until the end of the month. The maintenance of a population on Nos. 10 and 11 throughout 1934 is noteworthy, as the only food supply available consisted of the old fruits of the 1933 crop. After the crop shedding decrease of 1934 a relatively small but constant population remained on the trees feeding on the few fruits which survived the rains. Breeding was still taking place on these old fruits during March 1935.

The Relation between the Population on the Wild Host-Plants and the Incidence of D. fasciatus on Cotton.

Our observations indicate that the influx of this species into cotton is brought about mainly by a forced flight movement of stainers from *Thespesia rogersii*. It will be clear from the discussion of population fluctuations on this host that such movements, as they affect cotton, are most likely to occur at two periods during the year, firstly during the crop shedding decrease and secondly during the defoliation decrease. During these periods a wandering movement of adults in search of food is taking place. Evidence of this movement is afforded by the appearance of transient populations of adults on *Thespesia* trees which are bearing neither flowers nor fruit. Additional evidence is given by the appearance of similar populations of adults on *Hibiscus asper* and *H. cannabinus*. In actual practice the coincidence between the fall of the general population on *Thespesia* caused by crop shedding or by defoliation and the appearance on cotton is very striking, as may be seen from the figures illustrating seasonal distribution on cotton and on *Thespesia*. In 1932 the first appearance of the species on cotton followed the commencement of the crop shedding decrease and the influx continued over the period when stainers were flighting from the trees, rising rapidly during the early part of May when flighting from *Thespesia* was at its height. The relation was most clearly demonstrated during 1933 when, on account of factors which have been discussed, no crop shedding decrease took place. As a result very large populations were bred upon *Thespesia*. In some cases trees almost overhanging fields of cotton were carrying great numbers of nymphs and adults when not a single individual could be found in the crop, even at the time when cotton might be supposed to be in its most attractive state. In that year the first adults appeared in the field during June, coincident with the commencement of the defoliation decrease on *Thespesia*. It may be noted that by the time the species appeared in the field two pickings had already been taken and a delayed influx of this nature is of no material importance. In 1934 appearance of stainer on cotton was early and the influx again corresponded with the crop shedding decrease on *Thespesia*, which caused flighting of large numbers of stainers from January until April. In the case of the cotton on the station, this was not followed by breeding due to loss of the crop, but a further influx coinciding with the defoliation decrease took place in June and July. The leafing increase of 1934–35 was checked owing to defoliation of many of the trees by flight swarms of locusts which passed through the district in December and January. Thus the population was at a low ebb when rotting and shedding of the old fruit commenced and consequently the effects of food shortage were not felt until later in the year. By March most of the old crop had shed and a large proportion of the new fruits had been destroyed by the Cossid moth larvae. This resulted in the appearance of the stainer on cotton in small numbers in late March.

Summary.

A study of the variations of the population of *Dysdercus fasciatus* on cotton and on its wild host-plants is described.

The most important host of *D. fasciatus* in the Acacia savannah of Northern Rhodesia is *Thespesia rogersii*, and it is shown that at certain times a general flighting of stainer takes place from this host-plant caused by food shortage or defoliation. Generally a period of food shortage occurs during the earlier months of the year owing to rotting of the old crop and extensive destruction of the early new crop by the larvae of a Cossid moth. This causes an early influx into cotton, which leads to the establishment of a large population in the field at a critical period in the development of

the bolls. When the early crop is retained on the trees a continuously increasing food supply is provided, and this first movement does not take place. A second movement from *Thespesia*, which is largely due to defoliation, begins generally in June. It has been shown that a second influx into cotton coincides with this later movement from *Thespesia*. A late influx such as this is of little practical importance since the greater part of the crop is picked in May and June.

The observations recorded indicate clearly that the movement of *D. fasciatus* into cotton is not due to any attraction exercised by the crop but is caused by a forced movement of stainers from *Thespesia rogersii*.

References.

[1] Bebbington, A. G. & Allan, W. (1930–31, 1931–32.) Reports from Experiment Stations. Empire Cotton Growing Corporation,

[2] Clapham, A. R. (1929). J. Agric. Sci., **9**, p. 228.

[3] Pearson, E. O. (1934). Bull. Ent. Res., **25**, pp. 383–414.

[4] Bebbington, A. G. & Allan, W. (1934). Proc. Second Conf. on Cotton Growing Problems. Empire Cotton Growing Corporation.

A NEW SPECIES OF *CICADULINA*, CHINA (HOMOPTERA, JASSIDAE) INJURIOUS TO MAIZE IN TANGANYIKA TERRITORY.

By W. E. China, M.A.

The genus *Cicadulina* was established in 1926 (Bull. Ent. Res. **17**, p. 43) to hold a new species, *C. zeae*, China, injurious to maize in Kenya Colony. Later (Bull. Ent. Res., **19**, 1928, p. 66) it was shown that *Balclutha mbila*, Naude, recorded as transmitting the virus of streak disease of maize in Natal, also belonged to this genus, and two new species *C. arachidis* and *C. similis* were described from the Gambia, where they were reported as injurious to ground-nut and suspected of transmitting the virus of the rosette disease of that plant. Since that time Dr. H. H. Storey of the Amani Research Station has been investigating the possibility of transmission of the streak virus of maize by *C. zeae*. In attempting to breed strains capable of transmission of the disease certain crosses were made which showed conclusively that he was dealing with two distinct species. These species he was able to separate on the colour pattern of the abdomen. Dr. Storey has now sent to me material of both these species and a study of the genitalia corroborates his finding. One, of course, proved to be *C. zeae*, the other is new and I therefore propose to dedicate it to the discoverer.

Cicadulina storeyi, sp. nov.

♂. Head orange-yellow rather paler on clypeus and lorae beneath eyes ; two small black circular spots, one on each side of vertex just above and between but touching the ocelli ; eyes dark grey, whitish towards interior margin. Pronotum orange-yellow except along anterior margin behind eyes, where it is chrome-yellow. Scutellum chrome-yellow. Tegmina hyaline greyish yellow with costal margin and claval commissure narrowly yellow ; costal plaque white. In some specimens the tegmina

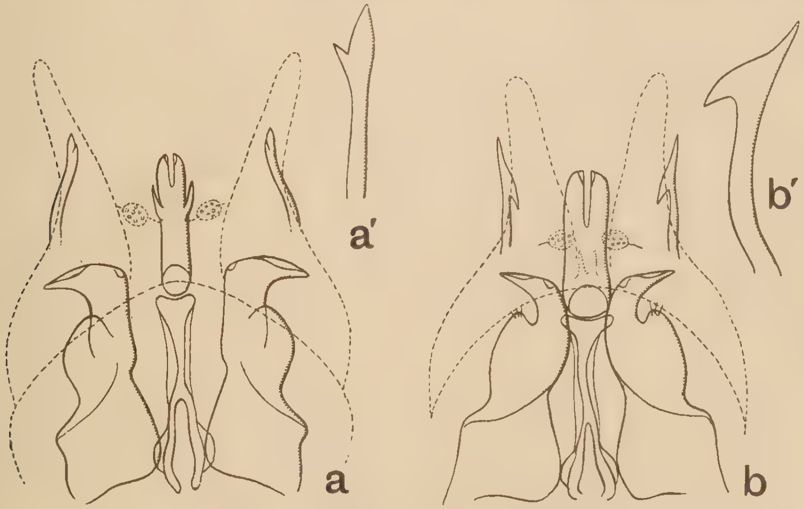


Fig. 1. *Cicadulina storeyi*, sp. n. : **a**, male genitalia in ventral view ; **a′**, lateral view of spine of pygophor.
Cicadulina zeae, China, Tanganyika : **b**, male genitalia in ventral view ; **b′**, lateral view of spine of pygophor.

tend to be opaque with a suspicion of the longitudinal fuscous stripe found in *C. mbila*. Wings hyaline, veins fuscous. Pleura whitish yellow margined with chrome-yellow. Legs pale yellow, the anterior tibiae more or less infuscate. Dorsum black with a narrow median longitudinal pale line and the lateral margins rather broadly chrome-yellow. Venter yellowish white. Aedeagus narrow, with one pair of appendages placed laterally beyond middle. Spines of pygophor slightly dilated at apex, with a short apically directed lateral tooth (fig. 1 a′).

Total length 2·8 mm. Width across eyes 0·7 mm.

TANGANYIKA TERRITORY: Amani; a number of specimens collected on maize and others bred from single females collected on maize, 1935 (*H. H. Storey*).

Closely resembling *C. zeae* in general appearance and differing only in the presence of a pale stripe down middle of back of abdomen and in the structure of the genitalia. *C. zeae* was described from females only. So far as can be ascertained the Tanganyika specimens with an entirely black dorsum are identical with *C. zeae* from Kenya, although it is impossible to be sure until topotypical males of *C. zeae* are available. The male genitalia of Tanganyikan specimens of *C. zeae* have been figured for comparison. The aedeagus is broader than in *C. storeyi*, with a contiguous divergent pair of appendages near base on the dorsal side; the spines of the pygophor bear toward the apex a posteriorly directed hook with a very broad base.

The genitalia of *C. storeyi* resemble those of the Gambian *C. similis*, China, but the aedeagus is narrower and the spines of the pygophor are not truncate apically and have only a single lateral tooth. It would appear that the spines of the pygophor show the most distinctive characters in this genus.

CURCULIONIDAE (COL.) ATTACKING CULTIVATED PLANTS.

By Sir GUY A. K. MARSHALL.

The types of the new species described below have been deposited in the British Museum.

Subfamily BRACHYDERINAE.

Protostrophus armatipes, sp. n.

♂♀. Derm black, with dense pale brown scaling; head with a paler patch adjoining the eyes; prothorax with a paler lateral stripe and an ill-defined irregular sublateral one; elytra often with faint sparse mottling of grey and dark brown, and nearly always with a distinct pale spot at the middle of interval 5 and another behind the middle of 3.

Head separated from the rostrum by a narrow sinuate furrow and with a deep median sulcus; the forehead somewhat flattened in the middle and sloping laterally towards the eyes, rather densely squamose and with subrecumbent brown setae; the eyes strongly convex, produced backwards for only one-fourth of their length, the orbit not projecting on the hind margin. *Rostrum* transverse (1·3 : 1), the apical width two-thirds that of the base; the sides sinuate, but the scrobes not visible from above; the dorsum flat on the basal half, with a broad transverse impression at the apex, and without any carinae. *Antennae* black; the funicle with joint one half as long again as 2, 4–6 equal and as long as broad, 7 transverse. *Prothorax* transverse (11 : 7), rounded laterally, widest at the middle, not constricted at the apex, with the apical margin truncate or very shallowly sinuate dorsally, the base arcuate; the dorsum strongly convex laterally and slightly so longitudinally, with close shallow punctation which is almost entirely concealed by the ovate scales and recumbent spatulate setae, leaving a bare impunctate median line which does not quite reach the base or apex. *Elytra* ovate, broadest about the middle, obtusely acuminate behind, and jointly sinuate at the base; the dorsal outline almost flat from the base to beyond the middle and vertically declivous at the apex; the shallow striae with deep separated punctures, which are more or less hidden by scaling, each containing a minute seta; the intervals broad and flat, each with two irregular rows of spatulate setae which are subrecumbent on the disk and suberect on the declivity; the scales ovate. *Legs* piceous, densely squamose; femora of ♂ only clothed beneath with long erect setae; tibiae with the hind corbels partly squamose, the front pair of ♂ strongly produced internally at the apex and close behind this a long stout forwardly-curved tooth, followed by two much smaller teeth; these structures on the front tibiae are much reduced in ♀. *Venter* clothed with narrow scales, except laterally on the two basal segments where the scales are broader; the setae unusually long and suberect in ♂, shorter and subrecumbent in ♀.

Length 4–5 mm., breadth 1·8–2·2 mm.

ORANGE FREE STATE: Ficksburg, 1 ♂, ii–iii, 1932 (*Mrs. L. Ogilvie*-type); Thabanchu, 9 ♂♂, 1 ♀, iv, 1932 (*J. S. Daniel*).

Reported by the Division of Entomology, Pretoria, as attacking young wheat.

Very similar in general appearance to *P. obliquecinctus*, Boh., which occurs in the Cape Province, but the latter species has the antennae testaceous, the front tibiae are quite simple, the femora of the ♂ have no long setae, and the scales on the venter are broad throughout.

Protostrophus sorghi, sp. n.

♂♀. Derm black, with dense sandy-grey scaling more or less mottled with brown; prothorax with a well-defined dark lateral stripe (not visible directly from above) and a broader paler median stripe, which is usually indefinite and sometimes obsolete; elytra with very variable mottling of dark brown; underside uniform pale grey.

Head separated from the rostrum by a shallowly curved fine stria which disappears laterally; the forehead smooth, somewhat flattened in the middle but sloping laterally down to the eyes, with a deep median sulcus; the eyes moderately convex, deepest a little behind the middle, projecting backwards for about a third of their length, but the hind edge of the orbit not produced. *Rostrum* three-fourths as long as the basal width, strongly narrowed from base to apex, with the sides shallowly sinuate, and the scrobes not visible from above; the dorsum flat, even, without any definite carina; the mandibles squamose. *Antennae* with joint 1 of the funicle a little longer than 2+3, 2 much longer than broad, 3–6 as long as broad, 7 slightly transverse. *Prothorax* transverse (9 : 7), not broader than the base of the elytra, rounded laterally, widest behind the middle, constricted at the apex for the reception of the eyes, the base subtruncate; the dorsum strongly convex transversely, flat longitudinally, quite smooth, with a fine median stria which is sometimes partly concealed by scaling. *Elytra* broadly ovate, widest at the middle, obtusely rounded behind, subtruncate at the base, the basal angles not projecting; the shallow striae exhibiting small separated punctures through the scaling, each containing a minute seta; the broad flat intervals with dense, partly overlapping scales equal to those on the pronotum and each with a row of subrecumbent spatulate setae. *Legs*: tibiae with two or three spine-like setae on the inner edge near the apex, the front pair dilated at the apex, with an apical row of five or six spines and another spine on the outer edge; the corbels of the hind pair squamose; joint 2 of the front tarsi as long as broad.

Length 2·9–3·8 mm., breadth 1·6–2·2 mm.

TRANSVAAL: Hectorspruit, 6 ♂♂ 14 ♀♀, xii, 1933 (*F. B. Jones*).

The adults are reported by the Division of Entomology, Pretoria, as attacking young kafir corn (*Sorghum*).

Very closely resembling *P. noxius*, Mshl. (Bull. Ent. Res. **10,** 1930, p. 274, Pl. xix f. 1), which, however, differs as follows: the transverse frontal stria is much more deeply sinuate in the middle; the prothorax is twice as broad as long and wider than the base of the elytra, without any median stria, the lateral margins being explanate and subdenticulate; the elytra are jointly sinuate at the base, and the basal angles slightly projecting.

Protostrophus cerealis, sp. n.

♂♀. Derm black, densely squamose; head with mixed grey and pale brown scaling, and a whitish patch adjoining the eyes; prothorax grey, with a very indefinite broad median brown stripe and a narrow one on each side of it; elytra mottled with pale fawn and grey, with a few brown spots in the striae, the suture pale fawn throughout; underside grey.

Head separated from the rostrum by a shallowly curved furrow covered with scaling and with a narrow median sulcus, the forehead flat and on a level with the upper margin of the eyes, which are moderately convex, highest behind the middle and project backwards for about one-third of their length, the orbit not projecting on the hind margin. *Rostrum* transverse (10 : 7), the apical width two-thirds that of the base, the sides almost straight, the scrobes not visible from above; the dorsum almost flat, with a very shallow median impression anteriorly and a feeble carina that is normally concealed by scaling. *Antennae* honey-brown; joint 1 of the funicle as long as 2+3, 3–6 as long as broad or slightly transverse, 7 broader. *Prothorax* nearly twice as broad as long, obtusely angulated at the sides a little behind the middle and constricted at the apex ; the apical margin deeply sinuate dorsally and subcarinate down the sides, the base broadly arcuate ; the dorsum convex transversely and slightly convex longitudinally, smooth and densely squamose except for a narrow bare median line. *Elytra* broadly ovate, widest a little before the middle, obtusely acuminate behind, broadly sinuate at the base, with the basal angles projecting somewhat beyond those of the prothorax ; the dorsal outline almost flat from the base to beyond the middle, the striae comparatively broad but very shallow, the punctures almost concealed by scaling and each containing a minute scale ; the intervals flat, with irregularly duplicated rows of recumbent brown setae, which do not become erect on the declivity ; the scales ovate and overlapping, smaller than those on the pronotum. *Legs* with two or three spine-like setae on the inner edge of the anterior pairs of tibiae only, the front pair not dilated at the apex, with an apical row of 8–10 very short spines and none on the external edge, the corbels of the hind pair partly squamose. *Venter* with oblong scales throughout, the last ventrite of ♀ with a broad transverse impression across the middle.

Length 4·6–5·0 mm., breadth 2·4–2·6 mm.

ORANGE FREE STATE : Thabanchu, 3♂♂, 1 ♀, iv, 1932 (*J. S. Daniel*).

The adults are reported by the Division of Entomology, Pretoria, as attacking young wheat.

Like very small specimens of *P. gonoderes*, Mshl. (Bull. Ent. Res. **17,** 1927, p. 201, Pl. xix, f. 1), which has a very similar prothorax but differs *inter alia* in its strongly tricarinate rostrum, the broader and deeper striae on the elytra, more convex intervals, and the suberect white setae on the declivity.

Subfamily APIONINAE.

Apion corchori, sp. n.

♂♀. Dull black, clothed throughout with sparse recumbent whitish setae, except for an indefinite darker subquadrate patch on the elytra about the middle of intervals 1–4, on which the setae are brownish and narrower ; the whitish setae are all arranged in a single row on the intervals, except on the basal fourth of interval 3 where they are duplicated and therefore more conspicuous, and similarly duplicated for a very short distance on intervals 2–4 immediately behind the darker patch.

Head sparsely setose, the forehead flat, shagreened, without striae or carinae. *Rostrum* short and stout, very similar in the two sexes, slightly longer than the pronotum in ♂ (3·5 : 3) and a little longer still in ♀, cylindrical, gently curved, not dilated above the antennae, which are inserted close to the base, their distance from the eye being only slightly greater than the length of the scape ; dorsum coarsely punctate, the punctures being slightly smaller and more separated in ♀, the basal area behind the antennae simply shagreened and impunctate ; no lateral sulci in front of the scrobes. *Antennae* with the scape as long as the two basal joints of the funicle; joint 1 of the funicle nearly as long as 2+3 and twice as broad as 2, the remaining joints becoming wider and shorter distally, 6 and 7 strongly transverse ; the elongate ovate club quite distinct from the funicle. *Prothorax* nearly as long as broad, gradually narrowing, much more deeply constricted near the apex than at the base, scarcely rounded laterally, the basal margin bisinuate with the lateral angles projecting ; the dorsum gently convex longitudinally, highest at the middle, shagreened, with very shallow separated punctures, each containing a recumbent seta, and a large rounded fovea in the middle of the base. *Scutellum* narrowly triangular, flat, with a depression on each side of it. *Elytra* ovate, with well developed shoulders, rounded laterally, widest at the middle, broadly and separately rounded at the apex ; the striae broad, with deep catenulate punctures ; the intervals as broad as the striae, convex, shagreened, each with a row of recumbent setae (partly duplicated), and a row of shorter finer setae in the striae between the punctures. *Legs* sparsely setose; the posterior pairs of tibiae in ♂ with a short stout mucro; joint 1 of the tarsi much longer than 2, which is longer than broad, the claws distinctly appendiculate.

Length 1·5–1·7 mm., breadth 0·5–0·6 mm.

South India: Coimbatore, 4 ♂♂, 3 ♀♀, bred from stems of the jute plant, *Corchorus*, xi. 1935 (*P. V. Krishna Ayyar*).

Of the described Indian species, nearest to *A. majorinum*, Fst. 1898, which is, however, a rather larger insect with reddish legs; the forehead is very shallowly 4-sulcate; the prothorax is longer than broad and more deeply constricted near the apex; the intervals on the elytra are broader than the striae, and the setae are broader and more scale-like, being much denser on the lower surface.

Apion (Piezotrachelus) ugandum, Wagn.

The late Mr. A. H. Ritchie, Government Entomologist, Tanganyika Territory, recorded this species as being a very serious pest of the native earth-nut or bambarra ground-nut (*Voandzeia subterranea*), a most important food crop in the Bukoba district. He added :—" The adult weevils are to be found in the soil round the collar of the plants, and oviposition takes place when the nuts or peas are well formed and beginning to harden. The interior of the pods is completely reduced to a brown faecal mass, much as is the sweet potato by *Cylas*. In this district the crop is planted in September and reaped in the following March, so the question arises what is the carry-over crop from March to September. It is believed by the natives (the Bahaia) that the pest is worst in years of heavy rainfall."

Subfamily ALCIDINAE.

Alcides obsoletus, Gerst.

This weevil has been received from Mr. H. Wilkinson, Entomologist, Kenya Colony, as a pest of sunnhemp (*Crotalaria juncea*), the larvae boring in the stems. The species, which was originally described from near Mombasa, is known to occur also in Nyasaland, Portuguese East Africa, and in the south-eastern districts of Southern Rhodesia.

Subfamily ITHYPORINAE.

Colobodes dolichotis, sp. n. (fig 1.).

♂♀. Derm piceous, with a background of dense brownish-black scaling with paler markings; head with brown or fulvous scaling, with a variable pale median stripe and sometimes a transverse pale band on the forehead; prothorax blackish, with a narrow pale median stripe which is wider at the base and sometimes dilated in the middle, and the whole lateral area grey; elytra blackish with a common narrow V-shaped whitish mark behind the middle (often more or less abraded) extending laterally to stria 3, with a broad transverse light brown band right across the base containing a paler patch at the base of interval 3 and darker patches on 4 and 5, the whole apical area pale buff or whitish, and intervals 1, 3, 5 with variable small patches of dark brown erect scales; the whole underside as far as ventrite 2 greyish with a few brown spots laterally and the last three ventrites dark brown.

Head with the scales erect and densely packed and with short stout clavate setae projecting a little beyond them, the forehead with a deep median fovea. *Rostrum* short, a little shorter than the pronotum, stout, moderately curved, with coarse longitudinally confluent punctures and dense scaling from the base to the antennae, the apical area bare and closely punctate. *Antennae* with joint 2 of the funicle slightly longer than 1, the three distal joints transverse. *Prothorax* nearly as long as broad, widest at the base, narrowing very slightly to beyond the middle then rapidly to the apex, without any subapical constriction ; the dorsum with convex scales on the apical area, but behind this the scales are erect and the larger ones more or less concave, across the middle a transverse row of four tufts of erect scale-like setae, the outer tufts pale and the inner one partly or entirely blackish ; a shallow median furrow in the basal half. *Scutellum* elevated, strongly convex, with one or two impressions, bare. *Elytra* oblong-ovate, length to breadth as 3 : 2, with deeply punctate striae, each puncture containing a broad horizontal seta, stria 6 reaching the base ; the intervals slightly convex, 1, 3, 5, 7 with numerous small tufts of erect scales. *Legs* grey or pale fawn with brown patches.

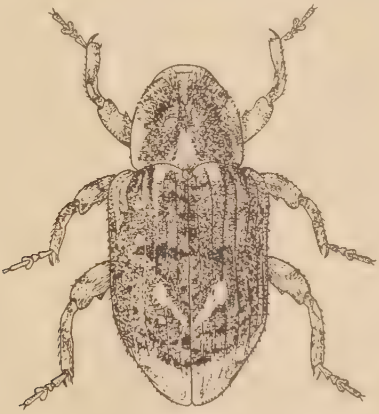


Fig. 1. *Colobodes dolichotis*, sp. n., ♀.

Length 7·0–7·5 mm., breadth 3·5–3·75 mm.

South India : Coimbatore, 1 ♀, 2 ♂♂, bred from larvae boring in stems of *Dolichos lablab*.

In the genotype, *C. billbergi*, Boh. 1837, stria 6 on the elytra does not reach the base but terminates behind the humeral callus, and the pronotum is clothed with very large separate flat round scales. A nearer ally is *C. ornatus*, Roel. 1875, from Japan, which has a similar V-shaped mark on the elytra, but it is a much broader insect (elytra 4 : 3), without any pale apical patch on the elytra ; the pronotum has no median furrow, and intervals 3 and 5 on the elytra have only four much larger tufts of scales.

Subfamily Baridinae.

Baris amaranthi, sp. n. (fig. 2.).

♂♀. Red-brown, with the pronotum usually paler and having a broad but sparse bilateral stripe of narrow separated transverse fulvous scales ; the elytra with an x-shaped sutural mark of whitish or yellowish scales, the anterior dilatation being at the base and extending to interval 3, the posterior one behind the middle and reaching interval 4 ; the sternum with separated yellowish scales, which become broader and much denser on the mesepimera and metepisterna.

Head bare, finely shagreened, with small scattered punctures. *Rostrum* about as long as the pronotum, deflected, moderately curved dorsally and almost straight ventrally, strongly punctate to the apex, with two carinae on each side, similar in the two sexes ; the punctures each with a short seta, and two or three suberect scales at the base above each eye. *Antennae* inserted at one-third from the apex, red-brown, short, stout ; joint 1 of the funicle as long as 2–4, 2–7 transverse and becoming shorter and broader distally, 7 twice as broad as long and fitting closely to the club. *Prothorax* very nearly as long as broad, parallel-sided from the base to beyond the middle, then rapidly narrowing to the shallow constriction, the apical collar unusually short ; the dorsum slightly convex longitudinally, highest at the middle, with fairly close deep punctures on the disk but with no definite impunctate median line, the punctures becoming much closer laterally, and on the pleurae coalescing to form irregular longitudinal ridges. *Scutellum* subquadrate, shallowly sinuate behind, bare, opaque. *Elytra* (7 : 4·5) only slightly wider than the prothorax, with the humeral angles very oblique, widest behind the shoulders, very gradually narrowing behind, jointly rounded at the apex, without dorsal impressions or posterior calli ; the striae deep and sharp, with faint distant punctures ; the intervals with a single row of small punctures, but these are more or less duplicated on 1–3 from the base to beyond the middle and on the basal third of 5 and 7 ; the punctures each bearing a short pale recumbent seta, and a few sparse narrow white scales. *Legs* red-brown, with fairly close but separated scales, the claws free. *Pygidium* of ♂ much more convex, with close deep punctures and very short inconspicuous pale setae ; that of ♀ flatter, more rugose and with much longer setae.

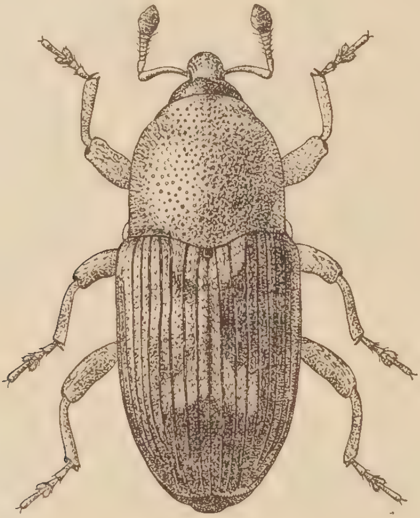


Fig. 2. *Baris amaranthi*, sp. n., ♀.

Length 2·7–3·2 mm., breadth 1·0–1·5 mm.

UGANDA : Kampala, 2 ♂♂, 5 ♀♀, bred from roots of " dodo " or native spinach (*Amaranthus polygamus*), vi. 1929, iii. 1934, v. 1935 (*H. Hargreaves*).

Belongs to a group of tropical species having a similar x-like marking on the elytra, such as *B. portulacae*, Mshl. 1916 (India), *B. multivaga*, Champ. 1914 (Seychelles), and *B. kakoense*, Hust. 1934 (Congo). The last-named, which is the nearest ally, differs in being of a shiny black colour ; joint 1 of the funicle only as long as 2+3, 2 being longer than broad ; on the pronotum the discal punctures are very small and widely separated, and there is an impunctate median line.

Baris dodonis, sp. n.

♀. Rather shiny black, with markings formed of sparse narrow whitish scales ; the pronotum with a broad sparse stripe on each side enclosing a small bare patch, and some scattered scales on the disk ; the elytra with a very short pale stripe at the base of interval 3 and a transverse band at the middle on intervals 2–4, and fairly numerous isolated white scales scattered on the rest of the surface ; the underside with a short whitish seta in each puncture, without any scaling.

Head with rather numerous small punctures right up to the vertex. *Rostrum* as long as the pronotum, very stout, deflected, moderately curved, rather finely punctate dorsally, with a smooth median line on the apical half, but the punctures becoming stronger laterally and rugosely reticulate above the scrobes. *Antennae* inserted at one-third from the apex of the rostrum, red-brown, short, stout ; joint 1 of the funicle as long as 2–4, 2–7 transverse, the distal joints wider. *Prothorax* nearly as long as broad, subparallel-sided or slightly narrowing from the base to two-thirds, then rather abruptly constricted, the apical collar moderately long ; the dorsum feebly convex, highest at the middle, with rather large deep close punctures on the disk, which are much wider than the intervals and leave a smooth subcostate median line, becoming larger and subreticulate laterally and somewhat smaller again on the pleurae. *Scutellum* subquadrate, slightly sinuate at the apex, opaque, impunctate. *Elytra* (8 : 5) distinctly wider than the prothorax, with well-marked humeral calli, subparallel-sided to beyond the middle, jointly rounded at the apex, with a transverse impression on intervals 3–6 at one-fourth from the base and obtuse posterior calli ; the striae deep, especially at the apex, with distinct separated punctures, striae 3 and 4 with an outward sinuation at the middle ; the intervals broad and flat (except at the apex where they are convex), with a single row of fine punctures, each bearing a curved dark seta. *Legs* black, with the tarsi reddish, rather sparsely setose, the tarsal claws free. *Pygidium* of ♀ strongly rugulose, without obvious setae, limited above by a curved carina.

Length 3·0–3·4 mm., breadth 1·4–1·5 mm.

UGANDA : Kampala, 2 ♀♀, from roots of *Amaranthus polygamus*, ii, 1934 (*H. Hargreaves*).

Apart from its colour and reduced scaling, differing from the preceding species, *inter alia*, by its shorter and much stouter rostrum, the subcostate and more narrowed prothorax, the non-confluent punctures on the propleurae, and the impressed elytra, with fine uniserate punctures on the intervals.

ASSESSMENT OF A TSETSE POPULATION.

By Ll. Lloyd.

The data on which this article is based were collected at Sherifuri, Nigeria, from October 1928 to February 1929. On the first three days of thirteen successive weeks collections of *Glossina tachinoides* were made in a secondary fly focus. At the end of each collection the flies were marked with a bold spot of oil paint on the dorsum of the thorax and passed through a bunghole into a large wooden box provided with a muslin cover. The case was then placed in a fixed spot in the thicket with the muslin cover darkened and the bung-hole open so that the flies could find their way out. A distinctive paint was used each week and flies caught bearing marks were released without further marking. The individual marked fly might thus be caught on several occasions but the intention was to keep the colony as intact as possible. The fly boys were instructed not to collect in the immediate neighbourhood of the release so that the marked flies recaught had again become part of the general population.

The fly focus was that around the Road Pond which has been described with photographs in the reports dealing with the work at Sherifuri (Lloyd, Johnson & Rawson, 1927). It is centred around the thicket bordering a narrow depression about a mile in length, full of water at the beginning of the dry season but drying completely or almost so, before the onset of the rains. The fly conditions had been subject to continuous study for the previous six years, during the last four of which the focus had been surrounded by a game-excluding fence. At the time of this experiment the fence had been opened and there was free access to the pool. In the course of five years neighbouring foci had been cleared of bush and the nearest spot harbouring *G. tachinoides*, except stragglers, was some 3,000 yards away. The focus was thus reasonably free from fly invasion during the dry season. Each October, the start of the dry season, the *tachinoides* colony was a thriving one but declined to small proportions before the rains began. The main cause of the decline is the reduction in food supply consequent on the shrinkage of the water. The recent studies of Buxton & Lewis (1934) and of Nash (1935) show that the climatic conditions from mid-October to February in this area are normally rather favourable than otherwise to this tsetse. The relative density and decline as indicated by the boy-hour catch for the season under consideration and for the three previous seasons is given in Table I (from Lloyd, Lester, Taylor & Thornewill, 1933). This shows that the decline during the experiment was not abnormal, though rather more rapid than the average. It is certain that the handling and marking did increase the wastage to some extent. When the active flies had been released into the cage a few feeble ones generally remained in the collecting boxes and these numbered 132, or 5 per cent, among 2,593 marked flies, but only 71, or 2 per cent., among 3,633 flies caught for the first time.

TABLE I.

The Relative Density of G. tachinoides *in the Focus as estimated by Boy-hour Collections.*

	1925–6	1926–7	1927–8	1928–9
Oct.	53	35	18	53
Nov.	62	29	30	44
Dec.	30	21	48	21
Jan.	14	5	30	8
Feb.	25	5	10	6
Mar.	27	scanty	6	2

The data collected are recorded in Table II. The three days collections and markings of each week are included in single groups and the analysis of the marked flies is shown horizontally, referred to time after marking. The recaptures of each colour group in the successive weeks after marking can be followed diagonally. Those caught one or two days after marking are excluded to avoid more complication. It will be evident that each colour group became very scarce on the fifth to sixth week after marking with great regularity. The rare individual fly might survive to ten or eleven weeks. It is also evident that the proportion of the colour groups recaptured increased steadily, with one exception, from 23 per cent. of the first to 52 per cent. of the eighth and then again declined. The increase is undoubtedly due to the fact that as population declines the fly boys were handling each week a larger proportion of the available fly (see Table IV). The cause of the ultimate decline is not so clear, but it is probably due to an increasing mortality in the final weeks of the experiment when the pool was drying rapidly.

TABLE II.

Showing the Details of Marking and Recatching G. tachinoides.

Dates of collection	Number collected	Number marked released	Colour	Distribution of recaught flies according to date of recapture interval in weeks after marking															Proportion of group recaught*
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Per cent.
24–26.x	1,710	1,587	dark blue																23
29–31.x	1,501	1,253	light green	167															28
5–7.xi	1,430	1,047	white	182	79														29
12–14.xi	1,629	1,065	pink	195	96	74													32
19–21.xi	1,317	775	brown	214	72	51	37												37
26–28.xi	940	535	yellow	176	93	17	16	7											40
3–5.xii	719	455	light blue	107	57	20	6	5	3										36
10–12.xii	679	428	dark green	90	61	29	7	8	1	0									52
17–19.xii	779	445	orange	122	47	33	13	4	3	1	0								41
24–26.xii	582	300	chocolate	117	66	19	8	7	1	1	1	1							31
31–xii–2.i	350	180	light grey	61	45	16	6	3	2	1	0	0	2						29†
7–9.i	321	177	dark grey	37	34	17	7	3	2	0	1	0	0	1					19†
14–16.i	135	81	red	23	9	6	5	5	0	0	0	1	0	0	0				10†
21–22.i	77			7	9	4	2	0	5	0	0	0	0	0	0	0			
31.i	33				0	1	1	0	0	1	0	0	1	0	0	0	0		
7.ii	65					1	1	2	0	0	2	0	0	0	0	0	0	0	

* *e.g.* 371 of the dark blue group were recaught from 1–11 weeks after marking, or 23 per cent. of the group, 1,587.

† 1 per cent. or 2 per cent. might have been added to these groups by continuing the experiment.

Further than this the writer was uncertain how best to handle the figures and so requested the help of Prof. P. A. Buxton after his study of tsetse in the Sherifuri area. Prof. Buxton has kindly spent much time over the data and has also discussed them with Dr. J. O. Irwin and Mr. W. H. Potts. The treatment of the data which follows is therefore made with the benefit of these discussions. It is considered that the material does not suffice for estimates of the length of life of the fly in nature, but that population can be assessed from them if the death-rate in the colour groups can be deduced.

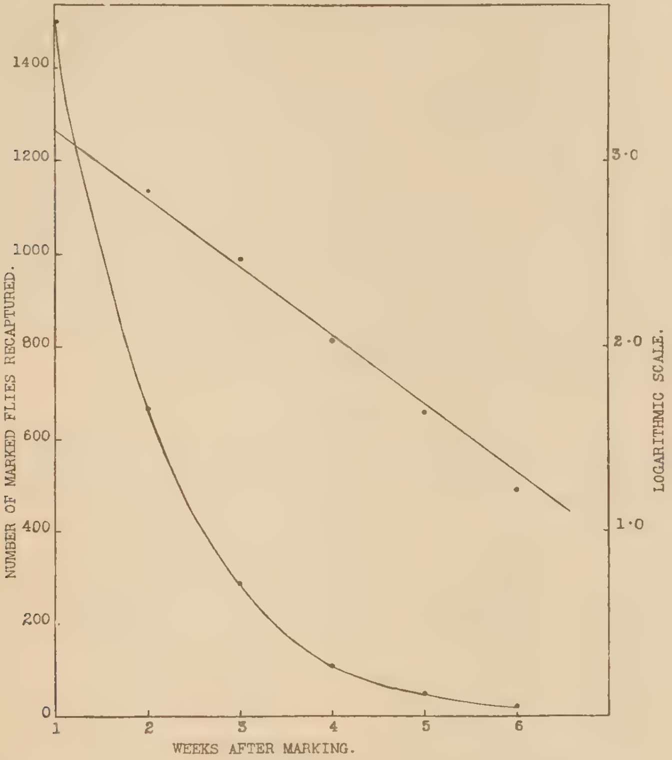


Fig. 1. Curve showing the numbers of marked flies caught at weekly intervals after marking. The line of the log. of a theoretical wastage of $11\frac{1}{2}$ per cent. *per diem* is shown and the points in its neighbourhood give the deviation of the curve from this.

The death-rate first suggested was 3 per cent. *per diem*, which is that assumed by Jackson (1933) in his attempts to assess the absolute population of *G. morsitans* by a method essentially the same. This death-rate seems a reasonable one, as balancing a probable birthrate in a stable population, but if applied to the present series of figures it gives an increasing population, whereas in fact this was definitely declining. In order to allow a large group to reach very small proportions in 5–6 weeks a wastage rate of about $11\frac{1}{2}$ per cent. *per diem* is necessary, and though this seems high, there is strong evidence that it is the correct factor to apply in this particular case. The total number of marked flies recaught from one to six weeks after marking respectively is as follows :—1,498, 668, 288, 109, 44, 17 ; a reduction of $11\frac{1}{2}$ per cent. *per diem* from 1,498 at seven-day intervals gives the series 637, 271, 115, 49, 21. The close correlation between the two series is shown in fig. 1. It is preferable to call this high factor a "wastage" rather than a death-rate, as some of the flies may have been leaving the focus and not necessarily dying in it. It seems a great assumption to say that the wastage was uniform throughout the four months but as each group died out in about the same time, it is probably the best working hypothesis.

Following the method applied by Jackson (1933) to the population in a closed area the calculations are as in the following instance. On 5–7 November 1,430 flies were caught, of which 182 bore marks given on the average 7 days previously when 1,253 were marked ; at a wastage of 11½ per cent. a day 533 of these are still alive in the area ; 182,533 of these were caught, so that assuming this factor represents the proportion of the whole population captured, this latter must be 4,189 flies. Further, 79 were marked 14 days before, and of this group 288 are available and the population is assessed at 5,213 for the same week. For the previous week one assessment is possible, 6,073, and for the week following three reasonable assessments can be made, 3,722, 3,850 and 2,685. The corresponding assessments have been worked out for the following weeks and are given in Table III. A fall from about 6,000 to about 400 during twelve weeks will be observed. The estimates based on flies marked one week previously are most likely to be correct as the numbers of the relative group surviving are then largest. Those based on flies marked two weeks previously agree fairly well, only two estimates being more than 25 per cent. out, less than the former. Of those based on flies marked three weeks previously one estimate is about 25 per cent. less than in the first series and two are greatly out, being about double the other assessments for the same weeks. Inspection of Table II will show that these bear reference to the groups marked white and pink respectively and that the wastage in these two by the third week had been abnormal.

TABLE III.

The population of G. tachinoides *calculated from catches of marked flies* 1, 2 *and* 3 *weeks respectively after marking. The highest possible population calculated on catches* 1 *week after marking without allowance for wastage is also shown.*

Date	11½ per cent. daily wastage. Collection after marking.			No wastage. One week after marking
	1 week	2 weeks	3 weeks	
29–31.x	6,073			14,264
5–7.xi	4,189	5,213		9,842
12–14.xi	3,722	3,850	2,685	8,746
19–21.xi	2,790	3,469	2,494	6,555
26–28.xi	1,762	1,950	(3,845)	4,139
3–5.xii	1,530	1,770	(2.952)	3,595
10–12.xii	1,461	1,079	1,399	3,434
17–19.xii	1,162	1,366	974	2,732
24–26.xii	942	684	1,074	2,214
31.xii–2.i	733	627	722	1,722
2–9.i	664	513	648	1,562
14–16.i	442	489	520	1,039
21–22.i	379	274	267	891

It is probable that the estimates are reasonably correct, with the exceptions mentioned, for there seems no doubt that the wastage factor employed has average accuracy and the numbers dealt with are fairly large. However, as the handling certainly caused the premature death of some flies, it may be as well to consider what

TABLE IV.

The Ratio of the Boy-hour Rate to the estimated Population of G. tachinoides.

Date	Boy-hour rate	Estimated population	Ratio	Weather
Oct. 29	51	6,342	124	Uniformly favourable for high catches till Nov. 14
30	51	6,073	119	
31	48	5,804	121	
Nov. 5	52	4,256	82	
6	50	4,189	84	
7	52	4,122	79	
12	60	3,855	64	
13	51	3,722	73	
14	51	3,589	70	
19	36	2,938	81	Cold with some haze
20	53	2,790	53	Bright and little wind
21	43	2,642	61	Bright, moderate wind
26	32	1,795	56	Cold, moderate wind
27	30	1,762	59	Cold and little wind
28	33	1,729	52	Cool, dull, little wind
Dec. 3	26	1,542	59	Cool, brief sun, little wind
4	24	1,530	64	Cool, brief sun, little wind, haze
5	27	1,522	56	Cool, bright, moderate wind
10	18	1,504	83	Very cold, slight haze, calm
11	19	1,461	77	Very cold, slight haze, calm
12	20	1,418	70	Cold early, warming with bright sun
17	26	1,193	46	Cool, bright, little wind
18	20	1,162	58	Cold, bright, strong wind
19	19	1,131	59	Cold, bright, little wind
24	18	972	54	Cool, bright, calm
25	23	942	41	Warm, bright, calm
26	18	912	51	Cool, bright, calm
31	8	742	93	Very cold, slight haze, little wind
Jan. 1	11	733	67	Cool, slight haze, calm
2	11	722	65	Cool, bright, little wind
7	9	696	77	Cool, bright, little wind
8	13	664	51	Warm, bright, little wind
9	11	632	57	Warm, bright, little wind
14	8	451	56	Cold, haze, strong wind
15	4	442	110	Cold, bright, strong wind
16	3	433	144	Cool, light haze, moderate wind
21	5	379	76	Cold, haze, strong wind

N.B.—The " haze " is the dusty obscurity often accompanying the harmattan wind. It was never dense during this experiment.

would be the population if there had been no wastage in these marked, as this gives an upper possible limit to the numbers. Calculated on the captures made the week after the marking these are of course rather more than double those based on a wastage of 11½ per cent. *per diem.* They are included in Table III. Even if it should be said that the population lies somewhere between these limits the information is of value, since one can get no idea of the absolute population of tsetse in a focus without such calculations as these, for only a relative value can be placed on the boy-hour catches.

It is worth while to consider what proportion of these estimated populations the boys did catch to the hour and these are given in Table IV with brief weather notes. The populations calculated from the first week's recatching are used and allowance is made for proportional decline during the three days of each series. It will be seen that at first the boys could catch about 1 in 120 available flies an hour and that as population fell the proportion increased to 1 in 70 on 14th November while the weather was uniformly favourable. The boy-hour rate, however, did not change importantly in these first three weeks of the experiment. If another factor, the hunger of the fly, was having increasing effect on the ease of catching, a similarly increasing proportion might be caught. After the third week, however, the boy-hour rate falls fairly steadily week by week with the declining population, allowing for the fact that some days were more suitable than others for fly activity. The proportion caught also goes up and down till near the end of the series, seemingly with weather conditions alone. At the very end of the series the numbers become erratic. It is not desired to labour the point too much but there does seem to be an indication that the boy-hour rate becomes approximately relative to population only when it is below 50. In one of the Tsetse Investigation Reports (Lloyd *et al*, 1927, p. 430) is stated " A skilful boy cannot net and box alive many more than a hundred flies an hour, even though they may be round him in a swarm, and variations from this number upwards have very little relative meaning." If the basis of the present calculations is reasonably accurate it seems that even less relative value must be placed on the boy-hour rate for any but rather small populations of tsetse.

No attempt is made to estimate the average longevity of the flies, but it may be observed that the length of life of the females was on the average greater than that of the males. The flies were not sexed at the marking but the sex of all recaptures was noted. Of those caught on the first and second days after marking there were 654 males, 57 per cent., amongst a total of 1,148 ; of those surviving one week 56 per cent. of 1,498 were males ; thereafter from the second to sixth weeks respectively the proportions of males were 49 per cent., 40 per cent., 28 per cent., 32 per cent., 23 per cent., *i.e.*, falling steadily with one unimportant exception. Flies which were caught from 7 to 11 weeks after marking numbered only 10 and these were all females. It is likely that these last 10 were not distinct individuals, but at least 5 individuals were represented amongst them as they occurred in 5 colour groups.

In writing up this work, which is so similar to that of Jackson (1933), it seems desirable to compare results obtained with the different species of fly. He worked in a racquet-shaped area liable to invasion from outside only by " the handle of the racquet." The area was 2½ square miles, and in this he marked male *G. morsitans* on 5 successive days, recatching and killing them on the 6th, 7th and 9th days respectively. He assumed an average life of a month and a death-rate of 3 per cent. a day, there being no suggestion that the population was not constant ; 378 flies were marked and 162 recaught among 720. From this he calculated a total population (both sexes) of 3,000 to 4,000 per square mile. The writer's area was a mile in length and the lateral range of the fly perhaps 100 yards, the initial population being of the order of 6,000. It seems that the results are not discordant, remembering the concentrating habit of *G. tachinoides* and the widely ranging one of *G. morsitans*.

Acknowledgment.

The writer is indebted to Prof. P. A. Buxton and to Mr. W. H. Potts for the discussion which preceded the preparation of this paper. Dr. J. O. Irwin has kindly read and approved the final draft.

Summary.

An experiment is described in which *G. tachinoides* in an isolated secondary focus was marked with distinct colours during thirteen successive weeks and the fate of the groups studied by recaptures. The population was known to be declining from moderate density to great scarcity through the dry season and the wastage in the colour groups on the average proved to be 11½ per cent. *per diem*, rather more, probably, than the wastage in unmarked flies. Following Jackson's method of assessment the population is shown to fall from 6,000 at the end of October to 400 by mid-January. The ratio of the boy-hour rate to these numbers is worked out for each collection and it is found that when the boy-hour rate is above 50 it is not relative to population, but below 50 the rate falls as the population, allowing for the influence of weather on rate of catching.

It is shown that under the conditions of the experiment there is an almost complete change of fly population each 5 or 6 weeks, though an occasional fly may survive 11 weeks. The proportion of male flies in the catches fell with increasing age from an initial 57 per cent. to 23 per cent. in the 6th week and no male fly surviving this period was caught.

References.

Buxton, P. A. & Lewis, D. J. (1934). Philos. Trans. Roy. Soc. London, (B) **224,** p. 175.

Jackson, C. H. N. (1933). J. Anim. Ecol., **2,** p. 204.

Lloyd, Ll., Johnson, W. B. & Rawson, P. H. (1927). Bull. Ent. Res., **17,** p. 423.

Lloyd, Ll., Lester, H. M. O., Taylor, A. W. & Thornewill, A. S. (1933). Bull. Ent. Res., **24,** p. 233.

Nash, T. A. M. (1935). Bull. Ent. Res., **26,** p. 103.

A DEVICE FOR THE RAPID COUNTING OF LARGE NUMBERS OF SMALL INSECTS.

By P. S. Milne, B.Sc.

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(Plate VI.)

During a series of experiments at Rothamsted with the mechanical insect trap described by Williams & Milne (Bull. Ent. Res. 1935, **26,** p. 543) it became necessary to make counts of large numbers of insects three or four times a day over periods of several weeks. The following is a description of a device which was designed to facilitate the handling of the insects and to increase the speed and accuracy of the counting.

The apparatus consists essentially of a turntable with a circular trough which takes the place of the stage of a low-powered binocular microscope with a wide field. On the right of the microscope is a funnel (fig. 1) which guides the insects on to the trough as the turntable is rotated. On the left of the microscope is a nozzle through which the insects are lifted by suction into a pill box after being counted. The dimensions of the turntable are related to the field of the particular microscope used for the counts and can be altered to suit any instrument which may be available.

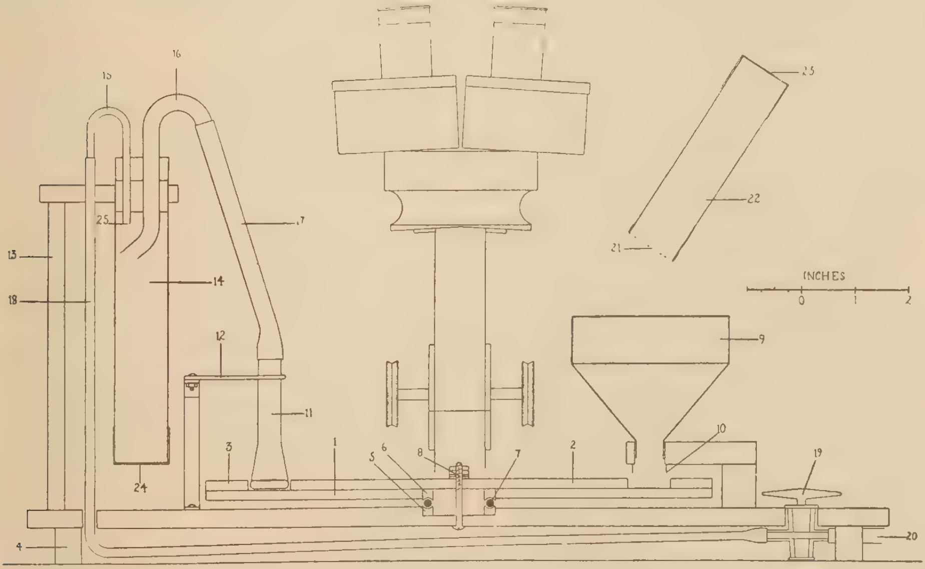


Fig. 1. Diagrammatic sectional view of the apparatus. The suction nozzle is shown displaced to the left for convenience of drawing.

The turntable is made up from three pieces of ⅛ in. three-ply wood. Two of these (1 and 2, fig. 1) are circular discs 24 cm. and 16 cm. in diameter respectively, and the third (3) is a ring of 24 cm. external diameter and 20 cm. internal diameter. When these are screwed together about a common centre a circular trough is formed $\frac{1}{8}$ in. deep and 2 cm. wide (*i.e.*, the width of the field of the microscope). A white circular card marked out radially into a series of numbered segments is inserted between the large lower disc and the upper disc and ring. The spacing of the lines and the position of the numbers are such that the latter appear in the centre of the trough and each section can just be seen as a whole in the field of the microscope.

The turntable is mounted on ball-bearings in the centre of a baseboard of five-ply-wood 16 inches square raised above the bench by four small feet (4) about one inch high. The ball-bearings are most conveniently constructed from two steering-head ball-races as used in a bicycle steering column. They can be obtained from most cycle dealers. One race (5) is pushed into a recess in the baseboard and the other (6) is sunk into the lower side of the turntable. The two are centred, with the necessary number of steel balls (7) between them, by a bolt (8) passing through the baseboard and turntable and secured by washers and lock-nuts.

The limb of the microscope is fastened near one edge of the baseboard by two bolts and milled nuts placed so that the trough in the turntable comes directly below the objectives. Then as the table is rotated each numbered section appears in turn in the field of view.

A small tin funnel (9) with the stem cut short is mounted above the trough on a wooden bracket at the far right hand corner of the baseboard. A short collar (10) of brass tubing slightly narrower than the width of the trough is fixed with glue on the underside of the wooden bracket in order to guide the insects as they fall down and to prevent them from rebounding off the numbered sections. A clearance of $\frac{3}{16}$ in. between the collar and the bottom of the trough allows the insects to spread uniformly as the turntable is rotated.

A suction nozzle (11) is made of brass tubing $\frac{1}{2}$ in. in diameter which has been squeezed carefully in a vice to give a parallel-sided orifice slightly smaller than the width of the trough. It is mounted in an inclined position opposite the microscope on a swivelling bracket (12) in such a way that it can be pushed up clear of the trough when not in use. A stop is arranged to prevent the nozzle fouling the bottom of the trough when in the operating position.

At the far left-hand corner of the baseboard is a wooden pillar (13) carrying a wide vertical glass tube (14) with the lower end about an inch above the baseboard. The top end is fitted with a two-holed cork carrying two glass tubes (15 and 16) bent as shown in the figure. The left-hand tube is connected by rubber tubing (17) to the brass nozzle above the trough ; the other is fitted with a long piece of rubber tubing (18) which passes down through the baseboard, and across underneath to the opposite right-hand corner to a glass cock (19) whose handle projects through a hole on to the upper surface of the baseboard. The other side of the cock goes (20) to a large bottle of thick glass, which in turn is connected to a filter pump on the water-supply. A ball-valve, such as is used for the inflation of football bladders, is inserted in the rubber tube between the bottle and the pump to prevent the former from being flooded by the back pressure when the water-tap is turned off.

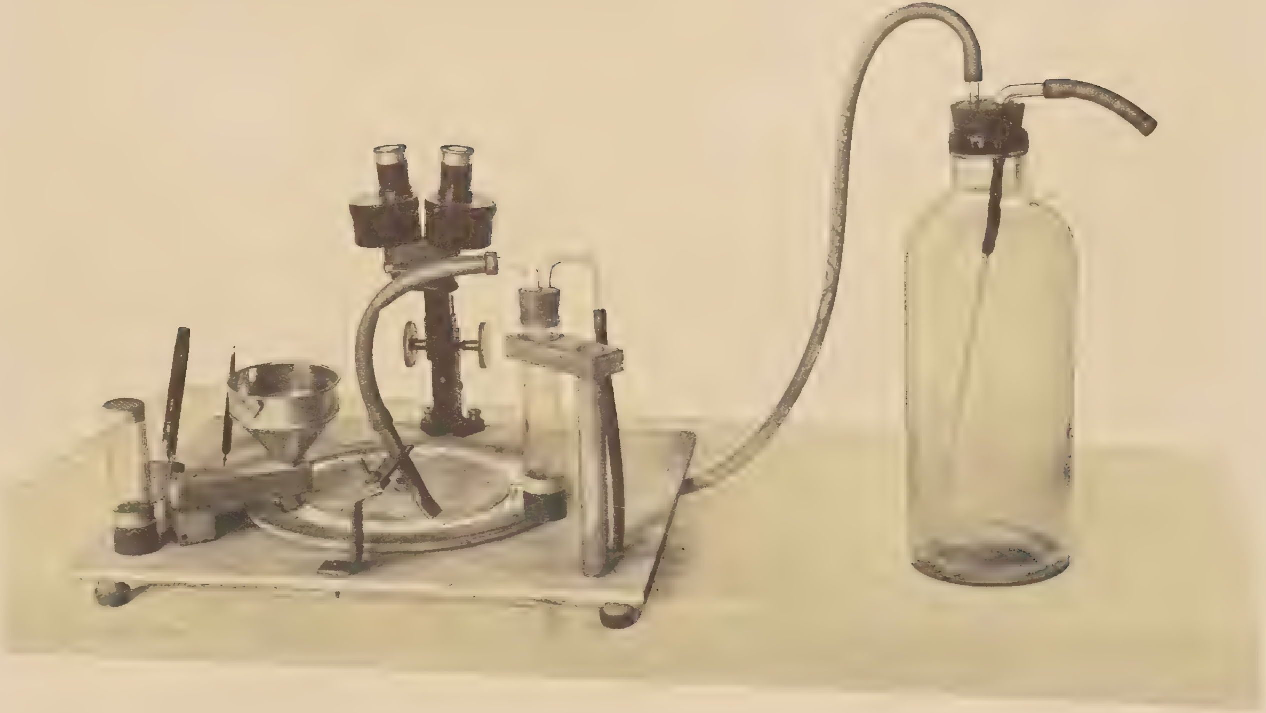
The larger insects are sorted out from the smaller ones by using a sieve consisting of a disc of perforated zinc (21) fixed with adhesive tape to one end of a short length of wide glass tubing (22). The other end is pushed into a pill-box (23), the width of the tubing being chosen to fit the size of pill-box which is to be used as a standard. The vertical glass tube on the left of the microscope is of similar size and also carries a pill-box (24) on its lower end. A convenient size for the holes in the zinc disc is $\frac{1}{10}$ in.

To use the instrument the insects to be counted are placed in a pill-box ; this is then pushed on the end of the sieve and the whole is inverted over the funnel and shaken gently while the turntable is rotated fairly rapidly with the left hand. The small insects are then distributed evenly over the trough and the larger ones remain behind in the tube to be counted macroscopically. If the total of small insects in the sample is likely to be greater than seven or eight hundred, the count should be done in two or more stages as the trough becomes rather overcrowded with larger numbers.

The table is then turned until section 1 is under the microscope and a count is made of all the insects on this section, or of all the insects of one species or family, according to the degree of analysis required ; section 2 is treated similarly and the numbers added mentally to those in section 1—and so on for a complete revolution of the turntable, when a note is made of the total. If family or specific counts are desired, further revolutions are made until all the insects have been scrutinized. Some insects, such as Aphides and Cecids, if required for further study, must be stored in spirit and these can be picked out with forceps as they are counted and thrown on to the central part of the turntable, to be picked up subsequently on a brush.

Towards the end of the counting the water-tap is turned on in order to evacuate the large reservoir bottle. The glass cock should be in the off or closed position. Then when the count is finished the nozzle is pushed home against its stop, the cock is turned on and the turntable rotated quickly in a clockwise direction. All the insects are lifted up to the top of the wide vertical glass tube, where they are shot against the side and fall to the bottom into a pill-box pushed over the end to receive them. The end of the outlet tube is covered with muslin (25) to prevent any stray insects from passing through and getting lost. Dust tends to collect on this muslin and it should be cleaned periodically by blowing air through in the reverse direction.

When all the small insects have been transferred in this way from one pill-box to the other, the latter is removed from the tube, labelled and stored for future reference.



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GENERAL VIEW OF THE APPARATUS ARRANGED FOR A LEFT-HAND WATER SUPPLY.

THE RELATIONSHIP BETWEEN THE MAXIMUM TEMPERATURE AND THE SEASONAL LONGEVITY OF *GLOSSINA SUBMORSITANS*, NEWST., AND *G. TACHINOIDES*, WESTW., IN NORTHERN NIGERIA.

By T. A. M. Nash, D.Sc. (Lond.),
Entomologist, Tsetse Investigation, N. Nigeria.

Introduction

Little is known about the seasonal variations in the longevity of tsetse-flies ; the subject is obviously of importance, because the longer the females live the more larvae they will be able to deposit.

The writer has previously shown that the seasonal longevity of *G. submorsitans* and *G. tachinoides* in captivity steadily decreases between January and April as the temperature rises, and that maximum daily temperatures in the critical zone (103°F. to 106°F.) are injurious to both species of tsetse, resulting in 100 per cent. mortality if 106°F. is reached (Nash, 1935). Results by Buxton & Lewis (1934, p. 181) on tsetses kept in incubators tend to confirm the writer's conclusions.

Two experiments have been designed to elucidate the seasonal fluctuations in longevity for both species :—

1. Experiment in a Grass Hut.

At the beginning of every month, during 1½ years, 105 freshly emerged tsetse of each species were placed outside the laboratory in a grass hut. The hut was built under the heavy shade of a Cassia tree ; it had no walls but a heavily thatched roof which extended to within 2½ feet of the ground. The tsetse cages were kept on a table, 2½ feet high, where they were protected from sun and rain, but not from wind. The climate within the hut compared closely with that found in a small, dense thicket in the open woodland—a site that forms a temporary fly habitat in the cooler months ; however, from March until May, when the heat is excessive, such thickets are evacuated by fly in favour of the cooler and more extensive patches of heavy residual forest. As far as possible the sexes were kept together in equal numbers—the female percentage over 18 months averaging 50 for *G. submorsitans* and 53 for *G. tachinoides*.

In fig. 1 the average lengths of male and female lives, for each monthly batch of 105 flies, have been plotted against the mid-day of life ; this has been done for both species. The annual cycle for one year only has been given ; both maximum temperature and rainfall are shown.

It will be seen that at the commencement of the rains in April 1934, when the temperature is maximal, the longevity of both species is minimal ; as the rains increase, so the maximum temperature drops, and fly longevity rapidly rises and remains high throughout the cool months of the wet season ; towards the end of the rains, the temperature rises, and in October and November, when the weather is rather hot, longevity tends to decrease. The hot dry season is interrupted in December and January by the advent of the harmattan wind, which, laden with fine dust, for a week at a time may partly obscure the sun, only a diffused sunlight penetrating the haze near mid-day ; at this season both maximum and minimum temperatures are very low and the maximum fly longevity is attained. In February the haze lessens, and soon the temperature soars up, reaching its maximum in March, April and May, when the parched and burnt up bush is excessively hot ; this rise in maximum temperature is rapidly followed by a decrease in longevity, which becomes minimal in April.

Clearly a remarkable degree of correlation exists between the maximum temperature and the longevity of each species ; minimum temperature does not show the same degree of correlation, because it remains almost steady from April until October. Similarly, saturation deficiency and evaporation fail to show so good a correlation ; to avoid confusing figs. 1 and 2, neither of these factors was incorporated, but the mean monthly figures for each, as taken in the grass hut, are given in Table I for the same period.

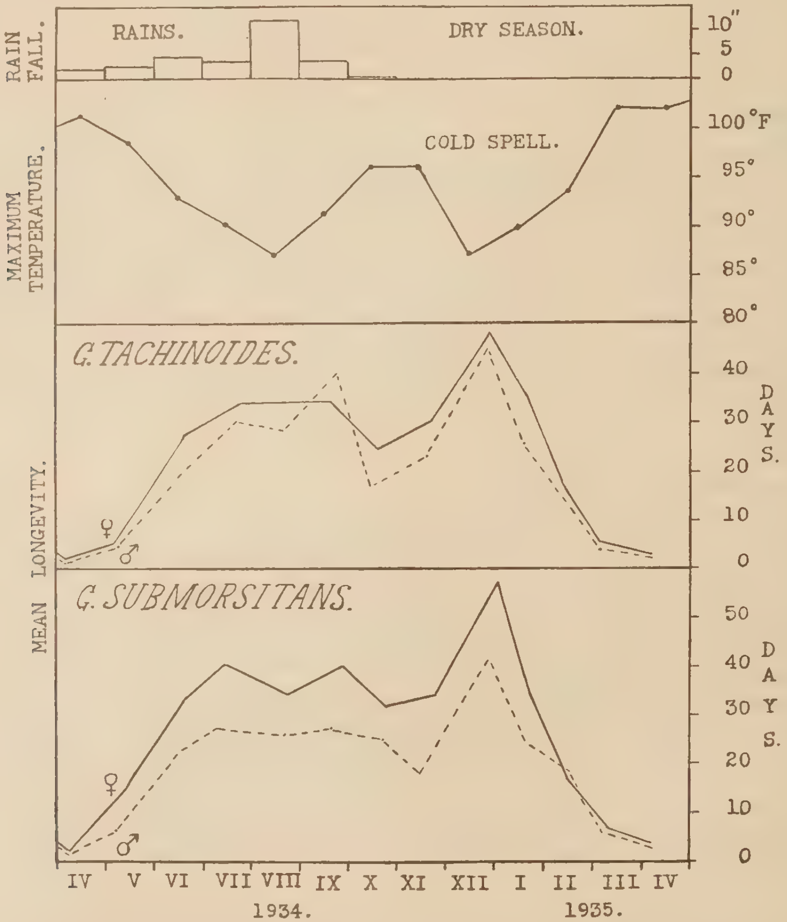

Fig. 1. The mean longevity of monthly batches of *G. submorsitans* and *G. tachinoides* kept in the grass house : males—dotted curve ; females—heavy curve.

TABLE I.

	1934										1935			
Months	iii	iv	v	vi	vii	viii	ix	x	xi	xii	i	ii	iii	iv
Evaporation in ccs. ...	58	47	28	19	16	8	11	22	40	40	40	53	63	63
Saturation deficiency in millibars	27	25	16	11	9	5	8	12	16	15	17	17	28	29

It will be seen from the table that in December 1934 and January 1935 both evaporation and saturation deficiency only paused in their rise, and, despite the great drop in temperature in the cold season, both remained at the November level. Now fly longevity was reduced in November, but rose rapidly in December and January, yet these two factors remained steady at the November level, so clearly it was not saturation deficiency and evaporation that caused the increase in the duration of life, but the maximum temperature which fell to favourable limits in the cold spell. Instruments in the forest showed that neither saturation deficiency nor evaporation even steadied in these months, but both continued to rise ; hence, in the cold season, when the desiccating wind blows from the Sahara desert, there can be no suggestion of an increase in humidity to account for an increased longevity.

In the hottest weather (March to May) the average life of the batches is only 3 or 4 days ; this gives a most exaggerated impression, because in nature the flies would not remain in the small thickets in open country (to which the grass-house climate is comparable), but would retreat into the dense residual forest ; nevertheless at this season longevity does decrease, even in the forest, as will be proved later.

Fig. 1 shows that with *G. submorsitans*, and to a lesser extent with *G. tachinoides*, the female longevity is usually greater than that of the male ; this fact has also been noted in *G. morsitans* by Kinghorn (1912), in *G. palpalis* by Fraser & Duke (1912), and in *G. pallidipes* by Harris (1930).

The greatest length of male life recorded in the experiment was 73 days for *G. submorsitans* and 93 days for *G. tachinoides* ; the greatest female life was 101 days for *G. submorsitans* and 116 days for *G. tachinoides*. These cases all occurred in the heavy rains, but it will be noticed that the greatest average life occurs in the cold season. The probable explanation is that exceptionally old individuals occur in the rains because they have many months of cool weather in which to attain great age, whereas in the cold spell the period of favourable low temperature is only two months ; however, the medium relative humidities (30–40 per cent.) of the cold season are probably more favourable to the community as a whole than the high humidities of the rains, and hence in the cold spell the *average* longevity is greater than in the wet season. Experimental evidence in favour of this supposition will now be given :—

With the temperature constant at 86°F., Buxton & Lewis (1934, p. 185) found that, using females of these species which were fed daily, the longevity was greater at humidities of 19 and 44 per cent. than at 65 or 88 per cent. Admittedly in the rains, when humidity is very high, the mean monthly temperature is only about 77°F., and in the cold season when humidities average about 33 per cent. the mean temperature is only about 70°F., so that possibly it is unfair to use in support their data based on 86°F. ; but on p. 187 of their paper it would appear that these authors intended to imply that even at 75·2°F. a high humidity percentage was unfavourable to *G. tachinoides*, but to a lesser extent than at 86°F.*

As stated, they also found that at 86°F. middle humidities of 44 and 19 per cent. were most favourable. Since the mean monthly temperature and humidity for March and April (the hottest season) is about 86°F. and 20–30 per cent. humidity, one would expect this to be a season favourable to long life, whereas in reality it is the most unfavourable of all seasons. The explanation is that humidity is only a minor factor in longevity and that the high maximum temperatures of this season more than counterbalance the favourable humidity, and so longevity is reduced. One can summarise the position by saying that :—

1. The rains are favourable to long life because the temperature favours it.

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* [I am grateful to Dr Nash for pointing out an unfortunate misprint in the paper by myself and Mr. Lewis. On p. 187 of our paper for "less unfavourable" read "less favourable." Dr. Nash's interpretation of our paper is correct.—P. A. Buxton.]

2. The cold season is probably most favourable to long life because both temperature and humidity favour it.
3. The hottest season, despite optimum humidity, is least favourable to long life because the maximum temperature is most unfavourable.

In other words, maximum temperature appears to be the dominant partner, and humidity can only influence longevity when the maximum temperature permits.

2. The Fly Marking Experiment.

The two obvious criticisms upon the results obtained in the last experiment are that caged flies may react differently to wild flies, and that from March until May the flies were kept in a higher temperature than they would have had to endure under natural conditions, because they normally evacuate the small thickets and concentrate in the residual forest, hence the great decrease in longevity shown for the hottest season may not occur in the field. In order to elucidate these points the following experiment was devised :—

Four times a month tsetse of both species were caught in the forest and marked on the thorax with oil paints ; they were then liberated. Some were eventually retaken, and their age at the time of recapture was noted. To obtain an index of longevity it was assumed that the last fly of the batch to be recaptured was approaching death at the time, and that it had been one of the youngest at the time of the marking ; thus, the day upon which the oldest recapture was originally marked was taken as its day of birth, and the date of its final recapture as its date of death ; the number of days intervening between birth and death was taken as a *conservative* index of maximal longevity for that season. There appeared to be no other practical way of approaching the subject, but it was hoped that these indexes would be sufficiently accurate to confirm or disprove the longevity cycle, as found under exact but artificial conditions.

During the rains it was possible to mark, monthly, 1,000 flies of each species, but during the dry season the number had to be reduced to 500 owing to scarcity of tsetse ; fortunately this reduction was not of great importance, as owing to the fly's habit of concentrating in the small residual forest during the dry season, the percentage of recaptures increased. In thirteen months 4·4 per cent. of *G. submorsitans* marked were recaptured, and 5·8 per cent. of the *G. tachinoides*.

The experiment continues, but to economise in space only the earlier part, which overlapped with the grass-house experiment, is shown in fig. 2. Owing to their reluctance to attack man, the females of *G. submorsitans*, and to a lesser extent, the females of *G. tachinoides*, could not be marked in sufficient numbers to be of value, and so the figures given are based upon males only. In order to bring the data from the grass-house experiment into line with the marking experiment, it has been necessary to take the *maximum* male longevity and not the average longevity as in fig. 1. The age of the oldest individual has been plotted against the mid-day of its life.

The maximal longevity curves for both species, under the artificial conditions of the grass hut, are given at the bottom of fig. 2 ; they agree with the curves for *average* longevity in fig. 1, with the exception, already dealt with, that whereas *maximal* age occurs in the rains, the greatest *average* age of the batch occurs in the cold season.

Comparing now the longevity curves for the marking experiment (see top of fig. 2) with those for the grass house, it would appear that tsetse live longer under artificial conditions, but this may be an illusion, because whereas under artificial conditions the real days of birth and death are known, in the marking experiment only a conservative index of maximal longevity can be obtained. Clearly the seasonal longevity cycle for both wild and caged flies is similar, in that longevity is high in the rains, falls with the rise in temperature in October and November, rises again in the cold season, and finally drops for the hottest months ; but it will also be noticed that every maximal and minimal point on the curve for the field is about a month later than the grass house. The probable explanation of this lag is that whereas flies kept in the grass house, in open country and at 2½ feet above ground-level, are immediately affected by a rise in temperature, those living naturally in the field can obtain a respite by first concentrating in the residual forest, and then, as the temperature continues to rise, by concentrating at mid-day on the forest floor, where the lowest temperatures are recorded (Nash, 1936). The wild flies will not be affected until the temperature rises on the forest floor, which will be obviously later than in the grass house from which the temperature curve in fig. 2 is taken.

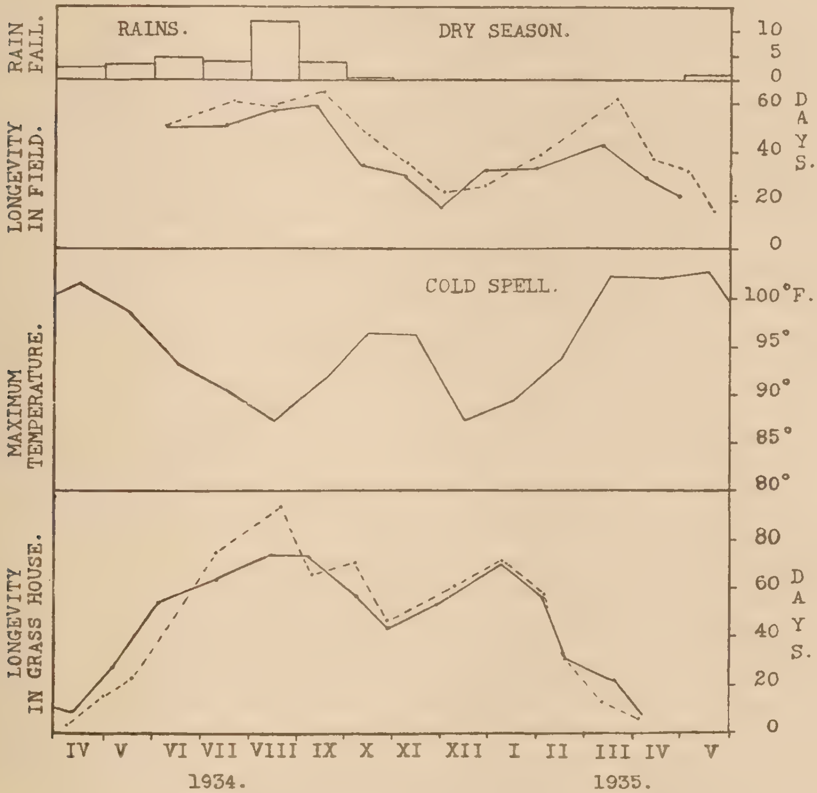

Fig. 2. The maximum seasonal longevity of male *G. tachinoides* (dotted curve) and male *G. submorsitans* (heavy curve) under natural and artificial conditions.

As was expected, in the hottest months longevity never became so reduced in the forest as it did in the grass house, but even so it was impossible in April to recapture a single *G. submorsitans* after more than 22 days, and in May, out of 830 *G. tachinoides* marked and 43 recaptured, the oldest was a female with only 17 days of known life. When the rains are late, the prolongation of the hot season must seriously affect breeding, as in May 1935, when puparia became exceedingly scarce ; but in years when the rains are early, longevity is probably only slightly reduced, because there will not be sufficient time for the forest floor to heat up before the rains start.

Throughout the whole marking experiment the oldest *G. submorsitans* ever recaptured had 64 known days of life, and the oldest *G. tachinoides* had 69 days ; these were not exceptionally old flies, as a considerable number of recaptures had about 60 known days of life, which suggests that, during the favourable cool weather, 2½ months is about the limit of life for *G. submorsitans* in the field ; since *G. tachinoides* appears to live slightly longer, 3 months may represent its maximal longevity. In the unfavourable hot weather one month probably represents the maximal age for either species.

It is considered that this marking experiment, despite the defects of its technique, confirms the conclusions founded on the grass-house experiment, namely—that the seasonal variations in longevity depend upon the maximum temperature.

In the only other work comparable with that described, Carpenter (1912, p. 80) marked 8,143 *G. palpalis* at Jinja in Uganda. The following results can be deduced from his data upon recaptures :—Flies marked in early August, when the mean daily temperature was 68°F., lived to a great age, but flies marked in early October, when the mean temperature had reached 73°F., lived a very much shorter time. This experiment, which is believed to be the only one published upon the seasonal longevity of *Glossina*, agrees with the writer's work to the extent that the average longevity of *G. palpalis* decreased as the temperature rose. Actually Carpenter attributed the decrease in the fly population to the falling humidity, but as the temperature was also rising there appears to be no reason why the decrease in population should not have been caused by a reduction in average longevity due to rising temperature. Wild *G. palpalis* must live to a much greater age than either *G. submorsitans* or *G. tachinoides*. Carpenter (1913, p. 7) records two males, which had been marked at the beginning of the rains, giving a known life of 247 to 253 days. The more equable climate of Lake Victoria with its much longer wet season probably makes such a degree of longevity possible.

General Summary.

1. There is considerable seasonal variation in the longevity of *G. submorsitans* and *G. tachinoides*, and these variations are negatively correlated with the fluctuations in the maximum temperature curve, *i.e.*, as the temperature rises longevity decreases, as the temperature falls so longevity increases.

2. The cycle is as follows :—The rains commence and temperature falls, longevity increases and remains high throughout the rains. The wet season ends, temperature rises and longevity descreases. The cold spell intervenes and longevity becomes maximal. The cold weather ends, the temperature soars up and longevity becomes minimal, remaining low until the new rains commence.

3. Maximum temperature is considered to be the dominant factor ; favourable humidity cannot increase longevity unless the maximum temperature is favourable.

4. The oldest individuals occur in the rains, but the average longevity is highest in the cold season, when both temperature and humidity are favourable.

5. In both species females tend to live longer than males.

6. In the field *G. tachinoides* males appear to live rather longer than the males of *G. submorsitans*.

7. It is doubtful whether wild flies of either species live much more than 2½ to 3 months under the most favourable conditions ; it is probable that in the hottest weather longevity is curtailed to a month or less, and that the production of puparia is seriously affected when the rains are late and the hot weather is prolonged.

Acknowledgments.

The writer wishes to make acknowledgments to Dr. H. M. O. Lester, Director of the Tsetse Investigation, for having made it possible for this investigation to be carried out. Acknowledgments are also due to Mallam Ibrahim who was in charge of the grass hut experiment and to Mallam Dau who carried out the marking experiment ; both these Hausas worked with great efficiency and intelligence.

References.

BUXTON, P. A. & LEWIS, D. F. (1934). Climate and tsetse-flies: Laboratory studies upon *Glossina submorsitans* and *tachinoides*.—Phil. Trans. Roy. Soc. London (B) **224,** pp. 175–240.

CARPENTER, G. D. H. (1912). Progress report on investigations into bionomics of *Glossina palpalis*.—Rep. Sleeping Sickness Comm. Roy. Soc., no. **12,** p. 79.

——. (1913). Second report on bionomics of *Glossina fuscipes* (=*palpalis*) of Uganda.—*Ibid*, no. **14,** p. 1.

FRASER, A. D. & DUKE, H. L. (1912). Various experiments.—*Ibid*, no. **12,** p. 75.

HARRIS, R. H. (1930). Report on the bionomics of the tsetse fly (*Glossina pallidipes* Aust.).—The Natal Witness, Pietermaritzburg.

KINGHORN, A. (1912). Notes on the preliminary stages of *Glossina morsitans*, Westw.—Bull, Ent. Res., **2,** p. 291.

NASH, T. A. M. (1935). The effect of high maximum temperatures upon the longevity of *Glossina submorsitans* and *G. tachinoides*.—Bull. Ent. Res., **26,** p. 103.

——. (1936). The part played by microclimates in enabling *Glossina submorsitans* and *G. tachinoides* to withstand the high temperatures of a West African dry season.—*Ibid.*, **27,** p. 339.

STUDIES ON SOILS IN RELATION TO THE BIOLOGY OF *GLOSSINA SUBMORSITANS* AND *TACHINOIDES* IN THE NORTH OF NIGERIA.

By P. A. Buxton,
Professor of Medical Entomology, University of London.
With an Appendix by K. Mellanby, Ph.D., M.A.

Introduction.

The extreme localization of breeding-places of *Glossina*, the fact that the larva is unable to penetrate many soils, and the possibility of making traps to which shelter and soil appear to attract the female fly, are all familiar ; they all point to the importance of soil in the life of *Glossina*. Moreover, when I was working with my colleague, Mr. Lewis, in the north of Nigeria in 1933, we found reason for thinking that the humidity of the atmosphere in the soil may act as a limiting factor upon the puparia of *Glossina tachinoides* and *submorsitans*. Exposing the puparia (under 1 day old) in glass tubes to controlled conditions of temperature and humidity, we discovered that at a continuous low humidity only a small proportion emerged (Buxton & Lewis, 1934, p. 214). For instance, when pupae of *G. tachinoides* were exposed at 30°C. to a range of different humidities, there was a steady fall in the proportion of emergences : at the lower end of the humidity scale 11 out of 12 puparia hatched at 98 per cent. relative humidity, but only 2 out of 15 at 11 per cent. The same effect, but less marked, was observed with puparia of *G. submorsitans*. It was also shown that many of the puparia exposed to the lower humidities died within a few days ; the rest lived all through the normal period but the resulting flies were unable to rupture the puparial skin and died within it. These unfavourable effects of low humidity were unexpected, for the country surrounding the laboratory was extremely hot and dry in March and April, at the culmination of the dry season. No rain had fallen for months, and the soil appeared to be quite dry ; the atmospheric humidity was very low (Buxton & Lewis, 1934, fig. 13) ; yet flies of these two species were common, and we found no evidence of high mortality among puparia in nature.

This apparent discrepancy between observations made in the laboratory and the field would be explained if one could show that the atmosphere in the upper layers of the soil is quite moist even at the end of the dry season. While we were in Nigeria, Mr. Lewis and myself made certain studies which have been extended in England on samples of soil which we brought back with us. This work shows that the thicket soil will take up and hold very large quantities of water, and that even when it has become nearly dry the atmosphere in its spaces is close to saturation.

It appears from our results, which leave much to be discovered later, that the relation of puparium to soil should receive much more attention than it has in the past. It seems hardly necessary to call attention to the importance of the soil atmosphere to innumerable other insects.

Contrast between Soils.

We shall limit ourselves to two different types of soil which occur in the neighbourhood of the Tsetse Investigation Laboratory at Gadau, near Azare, Nigeria (12°N., 10°E.). Close to the river one finds dense thickets, many of the trees in which are evergreen. These thickets are the " fringing forest " and " river bank association" of Lloyd, Lester, Taylor & Thornewill (1933). We are not here concerned with the vegetation but with the soil, which is dark brown, evidently contains a high proportion of leaves and twigs, and which would be judged by eye and hand to be rich in humus. The area occupied by the thickets and this type of soil is very limited. The other type of soil, which covers very large areas in this part of Nigeria, occurs further from the rivers. It is here that one finds the " woodland savannah " of the authors quoted above : this is an association of trees of many species, nearly all of them deciduous, and so spaced that one can walk through them in every direction. The soil here appears to consist of loose reddish sand and little else, and one is surprised that good crops of millet can be raised on parts of it after rain. Frequently the sandy soil is thrown up into ridges transverse to the prevailing wind, and these become partly consolidated into a sort of sandstone.

Collections of soil were made, in one area of fringing forest (Buxton & Lewis, 1934, fig. 12), and from a sandy ridge covered by woodland savannah, half a mile south of the laboratory at Gadau. In each place I took a dozen samples of soil, from the top inch only. The material was passed through a 1 mm. sieve, which only removed pieces of stick, none of the soil material being so coarse as to be retained. Equal quantities of the samples were mixed, to give a representative specimen of each of the two types of soil. Dr. B. A. Keen, F.R.S., of the Rothamsted Experimental Station, has been so good as to make a routine examination of these specimens. The results of his mechanical analysis, on oven dry and on ignited basis, and of his determinations of sticky point and moisture equivalent are given in Table I.

On these figures Dr. Keen makes the following comment :—" There is nothing much to say about the soil from the Sandy Ridge except that it is almost entirely a mixture of fine and coarse sand in the proportion of 3 to 1. The thicket soil is a soil

TABLE I.

Determination of certain Constants, in two Samples of Soil.

	Oven-dry basis		Ignited basis	
	Thicket soil	Soil from sandy ridge	Thicket soil	Soil from sandy ridge
Coarse sand	3·2	22·3	2·7	22·1
Fine sand	62·3	72·9	61·6	72·7
Silt	10·7	1·5	9·0	1·5
Clay	14·0	2·0	10·0	1·3
Carbonates	—	—	—	—
Air-dry moisture	2·5	0·2	2·5	0·2
Loss by solution	0·9	0·2	0·9	0·2
Loss on ignition	—	—	10·3	1·2
Difference	+6·4	+0·9	+3·0	+0·8
Total	100·0	100·0	100·0	100·0

	Thicket		Sandy ridge	
		Average		Average
Sticky point	41·2, 41·5	41·3	21·4, 22·0	21·7
Moisture equivalent ...	24·2, 24·5	24·3	3·7, 3·7	3·7

with 14 per cent. of clay and 10 per cent. of silt. The loss on ignition of this soil is high, and one may take it that there is a considerable amount of organic matter present. The sticky point and the moisture equivalent give a simple expression of the general moisture relationships of the soils. The low value of the moisture equivalent for Sandy Ridge merely confirms the fact that it is just sand with practically no water retaining power. The colloidal material in the Thicket soil is responsible for the high values of both measurements as compared with those for Sandy Ridge."

Experiments were also carried out by ourselves at Gadau, using the method described by Keen and Raczkowsky (1921), with more recent modifications about which Dr. Keen gave verbal information. The examination is carried out with a short cylindrical brass box, the bottom of which is perforated and detachable. A disc of filter paper is placed on the bottom. The sample of air-dried soil is then passed through a sieve of 100 meshes to the linear inch, the aggregations of soil being broken if necessary. The soil is loaded into the box, slowly and with constant tapping so as to assist it to settle ; ramming is not permissible. When the box is full exactly to the rim it is weighed. It is then set in a shallow dish of distilled water and left overnight for the water to rise through the soil by capillarity. As the water rises the soil expands, and eventually a columnar mass of "surplus soil" is left standing above the rim of the cylindrical box. The box is dried externally and weighed, and then the surplus soil is removed with a razor, flush with the rim of the box, and weighed.

The results obtained by this method are shown in Table II. The figures in the table are grams, obtained with a box of which the volume was 49 cc. The soil from "Thicket A" is that on which Dr. Keen carried out the analyses shown in Table I ; "Thicket B" was a very similar place about six miles away.

TABLE II.

Giving Weight (in Grams) of Soil examined by the Method of Keen & Raczkowsky.

Type of soil	Net weight dry soil*	Net weight saturated soil† (c–a)	Weight saturated soil less surplus	Weight saturated surplus soil (g–f)
Thicket A	59·2	88·7	77·3	11·7
"	54·2	87·1	74·0	12·9
"	54·4	88·0	73·9	14·1
" *mean*	*55·9*	*87·9*	*75·1*	*12·9*
Thicket B	61·0	93·2	72·5	20·7
"	61·6	95·0	72·6	22·5
"	59·5	91·6	73·4	18·3
" *mean*	*60·7*	*93·3*	*72·8*	*20·5*
Sandy ridge	84·5	100·9	97·1	3·9
" "	86·2	102·3	97·6	4·8
" "	83·9	102·0	97·6	4·3
" " *mean*	*84·9*	*101·7*	*97·5*	*4·4*

* Air-dry soil was used. Figures quoted have been corrected for water loss at 100°C., determined from a second sample.

† Corrected for weight of wet filter paper.

From these figures certain constants may be calculated (Keen & Raczkowsky, 1921, p. 444). Each of the following values is calculated from the means given in Table II.

	Thicket A	Thicket B	Sandy Ridge
Weight of 100 cc. air dry soil (gms.)	114	123·8	173
Amount of water taken up by 1 gm. soil ...	0·665	0·665	0·343
Pore space, per cent.	55·7	53·1	32·9
Specific gravity	2·20	2·01	2·46

The information given in Tables I and II and in the corresponding parts of the text will give a good idea of the two types of soil to anyone with the necessary technical knowledge. But it tells nothing about the point which we set out to study, that is to say, the humidity of the soil atmosphere in relation to the water content of the soil. It appeared that this could be studied by bringing a sample of soil into equilibrium with air of controlled humidity and weighing it. A special type of weighing bottle was designed, with an inlet tube below and an outlet at the top. A weighed quantity of air-dry soil (about 20 gm.) was put in it, the water content of the soil being determined by drying another sample at 100°C. A stream of air was bubbled very slowly through a succession of Woulff's bottles containing mixtures of sulphuric acid and water to bring the air to the desired humidity. This air was then passed through the soil in the weighing bottle, which was weighed daily till it reached equilibrium. This frequently took ten days or more at each humidity. The Woulff's bottles and the bottle of soil were maintained at a constant temperature (23°C.) ; this is necessary, because the mixture of acid and water gives the air a particular *relative* humidity, and

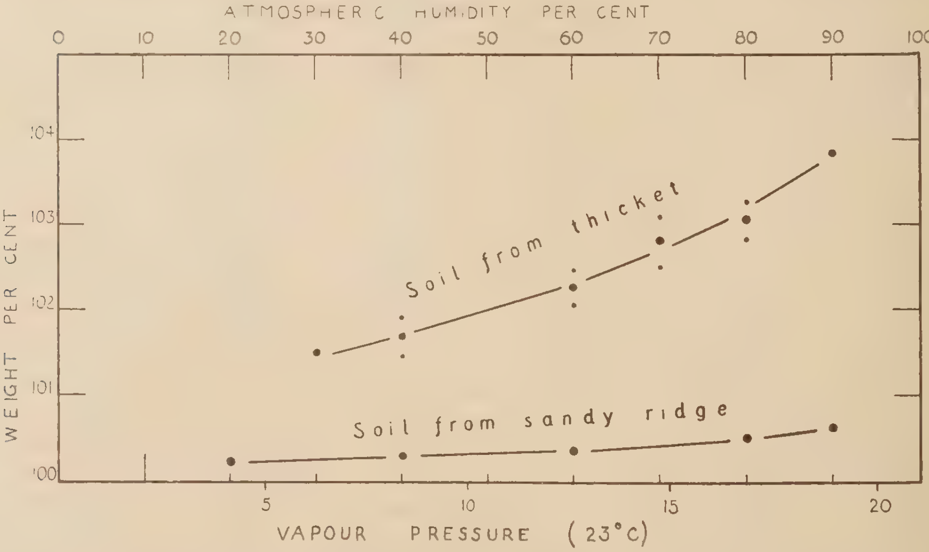

Fig. 1. Graph showing the percentage of water in soil of two types when it is in equilibrium with atmospheres of different relative humidities. The graph also shows vapour pressures (mm. Hg.) at 23°C., the temperature at which the work was done. The points are means of determinations made with humidity rising and falling, the values of which are shown as small dots, in the case of the soil from thickets.

any change in the temperature of the air will alter this. In an ordinary room the small sample of soil might change its temperature more rapidly than the large volumes of acid, so that for accurate work a constant temperature is necessary.

The results obtained in this way are shown in fig. 1. It is clear that there is a considerable difference between the two types of soil, for with air at 90 per cent. humidity, which is the highest humidity tested, equilibrium is reached when the water content of the thicket soil is nearly 4 per cent., but when that of the soil from the sandy ridge is about 0·6 per cent.

My colleague, Dr. K. Mellanby, describes (p. 287) a simple method by which the same result may be reached ; for nearly all soils, and for most purposes, his method is sufficiently accurate.

Discussion.

The facts set out in Tables I and II, and in fig. 1 may perhaps bear some such interpretation as this :—

1. The thicket soil* contains a high proportion of silt and clay (which make about ¼ of its weight on an oven-dry basis), and it loses 10 per cent. on ignition, showing its high organic content ; with this it has a high power of holding water (" moisture equivalent "). The experiments with the box show that it packs loosely, leaving a large pore space, and allowing it to take up a large amount of water. The soil from the sandy ridge consists almost entirely of coarse and fine sand, and is in all other particulars very unlike that from the thickets. In particular its power of holding water is very limited.

2. The fact that the thicket soil can take up so much water and hold it is important. Moreover, even when this soil is very nearly dry, with a water content down to 4 per cent., the atmosphere in its spaces is still close to saturation (fig. 1). So that when this soil seems to be absolutely powder-dry it might still provide the nearly saturated atmosphere which the puparium of *Glossina* seems to demand.

3. It would add materially to our understanding of the biology of *Glossina* in the north of Nigeria, if samples of surface soil could be collected in thickets and the loss of weight at 100°C. determined. If it were found that the loss exceeds 4 per cent., even at the end of the hot dry weather in March and April, one could perhaps assume that the soil atmosphere was saturated even at that season. It has not been possible to obtain this information, but *prima facie* it would appear that the presence of large numbers† of fly, and the absence of a high mortality in puparia is due to the water-holding properties of the colloids in the soils of the thickets.

Summary.

It is known that there is a high mortality in puparia of *Glossina submorsitans* and *tachinoides* if they are kept in air which is far from saturation ; it seems anomalous that there is no evidence of mortality among puparia in nature at the end of the dry season when the soil in the thickets appears to be quite dry.

Experiments are described, showing that the soil of the thickets (unlike the more sandy soil of the open country) will take up large quantities of water ; as its colloid content is high, this soil must also possess great power of retaining the water. Moreover even when the soil seems quite dry (water content 4 per cent.) the atmosphere in the soil spaces is very nearly saturated.

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*Differences may be observed between Thickets A and B and in certain particulars ; but on broad lines the thicket soils resemble one another and are unlike the soil from the sandy ridge.

† Dr. T. A. M. Nash, whose work at Gadau has now extended over about three years, is of the opinion that the number of flies at the end of the dry season is really very low : they appear to be numerous because they are concentrated.

It appears, therefore, but it is not proved, that the soil atmosphere in the north of Nigeria even under extreme conditions of heat and drought may not be so dry as to be unfavourable to the puparia of *Glossina submorsitans* and *tachinoides*.

References.

BUXTON, P. A. & LEWIS, D. J. (1934). Climate and tsetse flies : laboratory studies upon *Glossina submorsitans* and *tachinoides*.—Phil. Trans. Roy. Soc. Series B, **224,** pp. 175–240.

KEEN, B. A. & RACZKOWSKY, H. (1921). The relation between the clay content and certain physical properties of a soil.—Journ. Agric. Sci. **11,** pp. 441–450.

LLOYD, L. I., LESTER, H. M. O., TAYLOR, A. W. & THORNEWILL, A. S. (1933). Experiments on the control of tsetse-fly, Part II.—Bull. Entom. Res. **24,** pp. 233–252.

APPENDIX.

To Measure the Humidity of the Soil Atmosphere.

By K. Mellanby, Ph.D., M.A.,

Wandsworth Student, London School of Hygiene and Tropical Medicine.

This note describes how the humidity of the soil atmosphere can be measured reasonably accurately and simply. The only apparatus required is a clear glass jar of about 300 cc. capacity, fitted with an air-tight rubber bung through which a silver dew-point thimble projects into the upper third of the jar.

The procedure is as follows :—

To measure the humidity of the air in contact with the layer of soil, say that between three and four inches below the ground surface. First measure the temperature of that layer (by inserting the bulb of a thermometer for a suitable distance into the earth). Then quickly remove the top three inches of soil, and scoop up about 200 cc. of soil from the depth required (it may make things easier to mark the bottle with a conspicuous ring to show when it contains about 200 cc.). Replace the rubber bung firmly. The apparatus may now be taken to the laboratory and kept for some hours at a constant temperature, the same or slightly higher than that already measured for the soil three to four inches down. The relative humidity of the air in the space above the soil is measured by using the dew point method ; the relative humidity of the space in the bottle is very close to that of the air in the soil spaces.

At first sight this may appear inaccurate, but the following points should be noted : (1) The layer of soil in which we are interested will only be exposed for a few moments, during which time its water content will not alter appreciably ; (2) it might be thought that the loss of water from the soil to the space above it would materially alter the humidity of the air in the soil spaces. The water loss will actually be almost negligible. Even if the soil of the " sandy ridge " type described in the foregoing paper is used, 200 cc. of it would contain 1·2 gm. of water if the soil atmosphere were 90 per cent. saturated. If the temperature is 20°C., and if 100 cc. of dry air are added, the soil will have to give up only 1·6 milligrams of water—about 0·14 per cent.—to raise the humidity of the added air to 90 per cent. Quite dry air will be added very seldom, and most soils (as for instance the thicket soil described above) hold much more water. Therefore, the 100 cc. of air added will practically always take less than one-tenth per cent. of the water held by the earth, and this is negligible.

In the case of very sandy soil, the temperature at which the dew point is measured should be very nearly the same as the soil temperature. In soil with a high colloidal content the approximation need not be so close, though the temperature should never be below that of the soil in the field, as if it is and the humidity is high, dew may be deposited and it may take a very long time to reach equilibrium again.

Frequently it will not be necessary even to measure the dewpoint. The air in the soil spaces is often saturated and then dew may form on the sides of the bottle, and persist even at temperatures above that of the soil.

I believe that by the means described above the humidity of the soil atmosphere may be measured more accurately than by many more complex and expensive methods.

MINERAL OILS AS MOSQUITO LARVICIDES.[*]

By David R. P. Murray, M.A., Ph.D.

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Introductory.

Oil has been used as a mosquito larvicide for about forty years, since L. O. Howard in 1892 first recommended its use, and a large literature has accumulated on the subject, but the physical and chemical properties which make an oil a suitable material for this work are very imperfectly understood. It is clear that the problem is one that can very favourably be studied in the laboratory, for it requires above all an answer to the question "How do larvae die under oil treatment?" which can only be answered by microscopic examination of the larvae.

Various hypotheses as to the cause of death have been put forward, some of which can be ruled out at once. The early suggestion that larvae drown through inability to open their spiracles at the surface when oil is present can readily be disproved—no such inability exists. The view that they die from suffocation through mechanical inability to reach the air also cannot be for long maintained. For one thing, if larvae are prevented from reaching the surface they still live for considerable times; for another thing, the time taken to kill is so very different for different oils; and still again, fatal results may often occur even when large holes in the film give the larvae opportunity for frequently getting to the open air.

The suggestions that oil kills after penetration of the tracheal system either by simple asphyxiation or by acting as a contact poison or by vaporising inside the tracheae, are based on much surer grounds. The discovery that oils penetrate right down the tracheae and fill them to the entire displacement of air is in fact the most important observation yet made in connection with this problem. Many workers have commented on it: Hacker gives priority of observation to Takatsuki (1917), but the first clear account was by Freeborn & Atsatt (1918); it was the subject of intensive study by Hacker (1925), and also to some extent by Ginsburg (1929). These workers used oil stained with Sudan III or similar stain, but it has proved possible in the present work to make the observations on unstained oils.

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[*] The work here described was carried out in the Department of Entomology of the London School of Hygiene and Tropical Medicine and was financed in its entirety by a grant contributed equally by the Asiatic Petroleum Company, the Anglo-Iranian Oil Company and the Burmah Oil Company.

This possibility of oiling the inner surface of the tracheae is due to the fact that the material of which they are constructed is wetted by oils although not wetted by water. If pieces of trachea are dissected out of a larva and removed to a drop of oil, they are seen to change in appearance, losing their metallic look and becoming transparent. This change occurs with any sort of oil and indeed with nearly all organic liquids that are immiscible or nearly so with water, such as nitrobenzene, aniline, benzyl alcohol or caprylic alcohol. It also occurs with aqueous solutions if their surface tension is small, *e.g.*, it occurs with soap solution. Ethyl alcohol also wets them. The non-wettability by water is usually attributed to a layer of waxy material. This is supported by the experiment of putting a drop of boiling water on pieces of excised trachea. Although the pieces are not wetted in the same way as by the fat-dissolving organic liquids, their appearance is altered and clear patches are dotted irregularly over the unwetted patches producing a mottled effect, which could be due to the wax layer melting and becoming unevenly distributed.

The fact that oils penetrate the interior of the tracheae was made the starting point of the present work. Accepting it, we may ask a series of questions, each taking the problem one stage further backwards as it were. First, is the presence of oil in the tracheae invariably fatal to larvae? If it is, the perspective of the whole problem is shifted, and the search for a very toxic and quick-acting oil becomes secondary. The problem becomes merely to ensure that penetration takes place, and so we ask ourselves the second question: Does the presence of an oil film covering the whole of the water surface invariably lead to the penetration of oil into the tracheae of all the larvae under it? If this also is answered in the affirmative there will still remain a further question, namely, what properties must an oil have in order that a film of it shall remain uniformly spread over the whole surface of any water on which it is poured or sprayed? This third question is purely physical and chemical and will be discussed in a subsequent communication. In the present paper the endeavour will be to answer the first two.

There remains the possibility that the observations on penetration are all incidentals which do not relate to the cause of death. Conditions under which death occurs without penetration by oil will also be discussed here.

The Experimental Material.

The mosquito larvae used in this research were reared in the laboratory. *Aëdes aegypti* (*Stegomyia fasciata*) was bred in the method described by Leeson (1932).

Culex fatigans, which formed the mainstay of the experimental material, was bred in a rather simpler fashion. Larvae were hatched from egg-rafts in large enamel bowls, a pinch of ground-up puppy-biscuit being added daily. A certain number of the resulting pupae were placed in water in small bowls in cages where they emerged into adults. A canary was placed in the cage for a single night once a week, while slices of apple were added for the males. The females deposited their egg-rafts on the small bowls.

Anopheles maculipennis bred freely in an insectary, the females feeding on a rabbit and laying eggs on any water in the room. Eggs and young larvae were collected and placed in vessels of unglazed earthenware in which they fed on growing green algae. Adults emerged freely into the room. The culture maintained itself and survived the winter (the insectary being heated), but supplies of larvae sufficient for experimental purposes were only available in the summer.

Culex fatigans proved the most useful material because the tracheae stand out very clearly, and it is easily possible to discover whether larvae are " oiled " by examining the live larva under the 30 magnification binoculars, even when the oil used is quite colourless. Such a clear view of the tracheae cannot be obtained with *Anopheles maculipennis*, with which in many cases penetration of oil can only be determined by dissecting the larva.

The chief types of tracheal appearance noted in *Culex fatigans* are as follows. Normally the tracheae when viewed against a light background stand out as dark, almost metallic-looking tubes, distended with the air they contain so as to be approaching cylindrical shape. One change is that of deflation or collapse without penetration of oil, in which circumstances the tracheae appear as black tapes. Several different appearances are possible when oil is present. Sometimes the oil entirely fills the cylinders so that in shape they resemble the normal but are with a little practice easily distinguished by the loss of the dark metallic appearance. Under other conditions, although the air is entirely displaced, the tracheae are collapsed and have the appearance of light-coloured flat tapes. Under still other conditions the whole of the air does not get displaced but a cushion of air remains on one or both sides of the flattened part, so that a light ribbon with dark edges is obtained. The air cushion does not necessarily run the whole length, so that these last two conditions may alternate in the same trachea. Intermediate stages of tracheal collapse are encountered : in these they are not perfectly flat, but not so near to the cylindrical as is normal. There is however another intermediate state of some interest which seems to stand between the oiled and the unoiled condition ; this is a curious mottled condition associated with complete collapse of the vessels. This is particularly common with volatile materials and may be the result of condensation of vapour in isolated minute droplets ; on the other hand, it has also been observed with very poorly volatile products. All these appearances are recognisable in *Culex* without disturbing the larva.

Is the Presence of Oil in the Tracheae of Larvae invariably fatal ?

It seems possible to answer this question with a definite affirmative. In no case has a larva whose tracheae were filled with oil been found to pupate, although large numbers have been observed. The survival times vary very considerably, and if larvae are oiled with an oil of poor toxicity and then kept at a cool temperature (say 12°–16°C.) they may live for several weeks ; but even if placed in a vessel containing their normal nutrient medium they do not develop any further. Days after the control larvae from the same bowl have all pupated (an occasional control will die), the oiled ones, if still alive, will still be larvae, and eventually they will die in the same stage of development. It is doubtful indeed if they ever eat anything after being oiled (in some cases it is indeed certain that the gut itself is filled with oil). If a group of similar larvae oiled with a paraffinoid oil of almost no aromatic content be divided into two groups, one preserved with food and one without, no difference can be detected between their subsequent lengths of life.

Some experiments have been done in which a bowl of larvae was carefully searched for those on the point of pupation. Such larvae can be seen occasionally with the naked eye and with a low magnification are easily picked out by the appearance of the dark pupal trumpets inside the thorax. In these experiments a number were introduced under films and examined from time to time. Those which became oiled in the tracheae never completed the act of pupation, but all died in a fairly short time ; sometimes the first stage of the pupation process was begun and the thorax was split and part of the pupa projecting. This event is independent of the nature of the oil forming the film ; the long survival times described as being associated with the use of oils with very low or no aromatic content do not apply to larvae near the point of pupation, for these have never been observed to live for long when filled with oil.

In describing these experiments there are certain points which require emphasis. It is of course not practicable to have the larvae under continuous examination, and it may be that when the first examination is made—after half, one or two hours as the case may be—one or two have already pupated. In such cases the cast skins have always been examined. As a rule they are found to show no trace of oil, but a few exceptions have been observed. The question then is: are these sufficient to negative the conclusion that we have just drawn? There are reasons for disregarding these exceptions. For it has been shown that it is quite easy for a cast skin to get oiled when lifted through an oil film in a pipette and delivered on to a slide. Hence there is no evidence that these skins were oiled before their removal for examination, and the weight of other evidence, namely that no larva observed to be oiled has pupated, may be accepted as grounds for regarding these observations as an artefact. It may be added that these observations confirm those of the other investigators who have studied this point.

The criterion of death, in experiments with *Culex fatigans*, was complete absence of movement when viewed under a magnification of 30 diameters. The time of survival of oiled larvae was naturally a subject among the first to be studied, but it proves to be very variable. Some of the causes of this variability have become clear as a result of experiments described in later sections, and consideration will now be given to the second question enumerated on page 290.

Does the Presence of an unbroken Oil Film invariably lead to the Penetration of Oil into the Larval Tracheae?

If a simple answer to this question is demanded, that answer must be "No." But the conditions under which oil will or will not penetrate turn out to be not difficult of classification, and it becomes possible to make a correct forecast when the conditions are defined. Behaviour differs with the nature of the oil spread, and very markedly with the age of the film. It is necessary to make a sub-classification, taking into consideration the age of the film, boiling range and (rough) chemical composition of the oil used.

Fresh Films: Oils of Middle Boiling Range (200°–300°C. *approx.*).

At the room temperatures encountered (say 15°–23°C.) it was found that penetration was most rapid with oils of a boiling range of approximately 200°–300°C., though some higher-boiling fractions were as efficient, provided that they were not viscous. The quickness of penetration was studied in a series of experiments with short exposure times (10 mins.) carried out as follows.

A film of 10 μ thickness was obtained by spreading 0·2 cc. of oil on the surface of water 1 inch deep in an enamel dish 6 inches in diameter (equivalent to 1 cc. per sq. foot). Larvae were introduced under the film by pipette, six at a time. After 10 minutes they were removed and examined, another group of six being introduced. Nearly all the larvae were found to have oil penetrated into the tracheae; it was the exception to find one quite unoiled, though equally the exception to find one oiled the whole length in this time. The larvae were then passed through several washes of water and left in clean water. Examination an hour or so later showed oil along the full length of the vessels, proving that it is capable of creeping along; the remaining air gets displaced, the cubic content of the vessels being presumably lessened by partial collapse of the walls. The larvae in due course die. Thus it is demonstrated that 10 minutes' exposure to such a film in such circumstances is adequate to secure fatal results.

In other series of experiments an unlimited exposure time was allowed and it was observed that there were differences in behaviour which could be classified into three groups. The larvae might (1) all fall to the bottom after a few contacts and remain there; (2) all become entangled in the surface and lie there at full length;

or (3) behave as if normal and unaffected, in spite of the oil inside them. It was attempted to correlate these types of behaviour with physical or chemical properties of the oil. The first group belongs to the most toxic oils, such as Edeleanu extracts (aromatic concentrates obtained by extraction with liquid sulphur dioxide), two which showed it very markedly being " Gasex " (Shell Co.) and the SO_2 extract of " Long Time Burning Oil " (Anglo-Iranian). Group 2 is associated with oils containing high paraffin content—paraffins have a very poor toxicity and larvae live lying in the surface for long periods. This property of paraffins appears, however, to be physical rather than related to their non-toxicity, for larvae were equally caught in the surface with some very toxic oils of about half and half paraffin and aromatic content such as " Boxol " (Shell Co.). It did not prove possible, therefore, to make a strict line of demarcation. Most characteristic of group 3 is the Burmah Oil Co. product " Malariol " (Assam formula). This falls into the class of rapid penetrators, although its boiling range is higher. Fully oiled larvae hang in the resting position with their spiracles attached to the surface and re-attach themselves in the same way after swimming around.

Survival Time as a Function of the Amount of Oil taken in.

It now becomes possible to give some explanation of the very wide divergences of survival time, which is one of the earliest observations. It is in some cases due to the difference in the amount of oil taken in. Larvae which do not rise to the film after more than one or two contacts may get very varying dosages of oil, though the creeping action will cause the tracheae to be filled in time. Corbett & Hodgkin (1931) in a similar connection concluded that oil might enter the spiracles at each contact with the film :—" The probability of oil entering the spiracles and the total amount which enters will therefore vary directly with the number of times the larva makes contact with the surface and the thickness of the film." With this view the present work agrees, and it can be added that this number of contacts is in general smaller with increased toxicity of the oil. Fortunately in these cases the difference is not important, as a very small intake proves sufficient to oil the whole length with the inevitable fatal results.

With those oils that cause Culicine larvae to lie full length in the surface interesting differences in the amount of oil taken in are found between the surface ones and the minority which lie on the bottom. The latter nearly all show collapsed tracheae, while those in the surface have them distended to the full with oil, so that if they are dissected and the excised tracheae pressed with a needle bubbles of oil are squeezed out. The probable explanation is that continued access to the oil has caused more and more to flow in, the ones on the bottom having sunk there while still only partly filled. There is admittedly an alternative explanation, that being filled with oil causes the larva to float by lowered density. If the oil is moderately toxic, it will now be found that those with tracheae distended and filled with oil will die much sooner than those with collapsed tracheae and lessened oil content. Such a result was, for instance, obtained with an oil consisting of refined kerosene in which was dissolved a little naphthalene. Larvae were subjected to oiling from this mixture and left overnight. Those with distended tracheae were dead ; the survivors all had tracheae collapsed or nearly so. A similar result was obtained with " Malariol " (Assam formula). Those larvae which hang normally oriented to the surface generally show their tracheae filled out with oil, while those lying on the bottom usually have them more or less collapsed. A set of oiled larvae from a single experiment was divided into two, according to whether the tracheae were filled out or collapsed ; none of the former group survived more than about 24 hours, but several of the latter group lived 4 or 5 days. In a previous experiment in which 16 larvae were left overnight under a film, when examination was made, it was shown that all the surviving ones were collapsed, those with distended tracheae being all found among the dead. That collapse of the tracheae should prolong life is at first sight paradoxical, since in the normal larva collapse is a symptom of sickness, often itself fatal; it is evidently due to the difference in the dose of the toxic constituent.

It is also the difference in dosage that causes the irregular results obtained with very thin films. Some experiments were done with films of " Malariol " (Burmah formula) of only 2 μ and even 1 μ thick. With the 2 μ film, 4 out of a batch of 8 showed oiling after 10 minutes, though only 1 out of the second batch of 8. But leaving the rest under the film, all except one became oiled in time; this one exception, however, pupated successfully. With the 1 μ film, which is so thin as to show colours, of 16 larvae only 3 could be found to have become oiled in half an hour, but all but one were oiled in 2½ hours; this one, still unoiled after 4 hours was killed. In a second experiment with a 1 μ film the larvae were left 2 hours before examination and all but one showed oiling, this one receiving oil later on. An interesting feature of the experiments was, however, that the average survival life of the larvae after becoming oiled was much longer than the normal for this oil: several lived for upwards of a week, most of them from a half to one week, as against the normal survival time of under 6 hours, but none succeeded in pupating. This must be interpreted as saying that they received only a very small dose from touching these very thin films, a fact which was borne out by inspection, for several were oiled so thinly that their tracheae had not completely lost their opacity but had the appearance described as mottled.

Oils of Boiling Range above 300°C.

Many oils of high boiling range prove less efficient than middle-boiling fractions owing to their higher viscosity, which leads to a failure to penetrate the larval tracheae. The limit of range of quick-penetrating oils will of course be dependent on the temperature, and some oils which in this laboratory have failed to oil larvae with certainty will without doubt prove adequate in warmer climates.

" Spinex " (Shell Co.), an Edeleanu extract of boiling range 295°–395°C., an SO_2 extract of lubricating base supplied by Burmah Oil Co., and an " Untreated 50-Grade Oil " (Anglo-Iranian) were among samples studied. With " Spinex " the following results were obtained:—

13°C.	(February room temp.)	Five out of 16 unoiled after 5 hours.
17°C.	(September ,, ,,)	Only 4 out of 16 unoiled after 30 mins.
22°C.	(July ,, ,,)	Seven out of 16 unoiled in 20 mins. (2 unoiled in 3 hours).
28°C.	(Incubator)	Three oiled in 10 mins.; all but 2 oiled in 2½ hours.

Thus even under warm conditions this oil is too viscous to be an efficient material, and in experiments with the other two oils mentioned above the same type of result was obtained.

Oils of Boiling Range below 200°C.

The results obtained with oil cuts in the more volatile range have proved very interesting and not entirely expected. Field workers have generally rejected these fractions on the ground of their volatility, but most have considered that they were in fact more toxic if only access to them by the larvae could be assured.

As a preliminary to the study of this question, some experimental work was done under highly artificial conditions in which a single larva was taken and treated with a single drop of oil in a hollow slide, the larva being allowed to wriggle on the slide freely. Under these conditions the time of oiling is progressively shortened with increased volatility, benzene and toluene passing up the tracheae in about 1 minute or less, middle cuts taking (on the average) 3 to 5 minutes, while at the other end " Untreated 50-Grade Oil " took 10–12 minutes, SO_2 ext. of kerosene

(Anglo-Iranian) cut boiling over 240°C. 8–12 minutes, SO_2 ext. of kerosene (Burmah) cut boiling over 245°C. 6–10 minutes. (The shortness of all the times is due to the fact that wriggling violently undoubtedly results in the oil being forced along more rapidly ; this has been observed quite frequently and is a source of difficulty in experiments where the time of oiling from a film is being investigated ; for the larvae with only a trace of oil in the siphons may oil up their whole length during the brief moment of examination).

From these preliminary experiments one might expect that volatility would not be a serious handicap for field purposes, for a very few hits would result in the larvae becoming oiled. Actually, however, the situation is found to be quite different. If the experiment of removing the larvae after 10 minutes is tried, it is found that a number of the larvae, which may be nearly a half, are unoiled ; the oiled ones die very rapidly, and their survival time is extremely small, but it is the behaviour of the others that is interesting. The first point about them is that all have their tracheae completely collapsed. After a few hours it is found that some of them are dead with their tracheae still in this state, a few showing the mottled appearance but some without any detectable trace of oiling ; of the live ones, however, some have redistended their tracheae with air and have taken on the appearance of plain normal larvae. Some in fact do proceed to pupation, although it has been noticed that several in this class have later suffered re-collapse and ultimate death. Those larvae which have not redistended their tracheae have all died, although after varying lengths of time, all, however, greatly outliving the oiled larvae.

It is to be assumed that it is because of the collapse of the tracheae that the larvae escape having them oiled in the short time allowed. The conclusions of Corbett & Hodgkin are again worth quoting. They considered that at the first contact a small quantity of oil enters and this causes collapse of the main trunks "though their contents are still mostly air ; whilst the effect is frequently fatal, larvae may pupate and adults eventually emerge." This is very near to the truth, but with non-toxic oils direct motion of oil up the tracheae without any collapse may be observed, so that collapse cannot be attributed just to contact of liquid with the tracheal walls ; it is more probable that vapour causes the collapse through some irritational effect.

Freeborn & Atsatt concluded that it was vapour which was the real toxic agent in all cases except where the survival time after oiling was so long that it equalled the time taken to asphyxiate the larva. They incline to reject the view that liquid oil acts as a contact poison, though there seems to be no reason why, in different circumstances, the cause of death should not be any of the three, sometimes mere suffocation, sometimes contact poisoning by liquid oil (whatever such a statement may mean physiologically), and sometimes death from vapour even when air is not altogether excluded. But whereas in the first two of the causes, the process once initiated cannot be reversed, that is to say, when oil is inside the tracheae it cannot be got out, vapour asphyxiation is up to a point reversible and the larva may recover. That it does not often do so in these cases is due to the fact that a small amount of actual liquid oil generally enters as well. The explanation offered of the phenomena as encountered in this work is as follows. Larvae touch the film of the volatile oil and in some cases oil enters just as with the other oils, but in a minority of cases (and possibly not at all, if the film is really thick, say 15 μ or more) the contact with the film causes entrance of vapour which has an irritating effect resulting in the immediate collapse of the main trunk. The larva very possibly dives from the surface at once and does not return, or in any case the possibility of oil entering is much reduced by the reduced space available and by the two surfaces being flat against one another. When toluene was used to form a film on an open dish, it was all evaporated in about five to ten minutes after having produced considerable surface agitation. But nearly all the larvae died, though they were alive when the last traces of toluene disappeared ; and only one or two were oiled, so that the majority must have died from the effect of vapour (the absence of oiling or at least the absence of a continuous oil layer was always confirmed in cases of any doubt by dissecting out the tracheae and transferring to a drop of oil on another slide when the immediate change of appearance was noticeable).

Experiments on Exposure to Oil Vapours.

Several workers have described experiments in which larvae were exposed to the action of oil vapours. It cannot be expected that such experiments will yield results which will rival in rapidity the effects of the volatile oil cuts. Freeborn & Atsatt have already pointed this out. It is the intimate contact obtained only by hitting the film of liquid that enables the full effect of vapour to be brought out. Exposure to vapour experiments carried out in this study have shown that the effect is very slow indeed. The experiments were carried out in desiccators. A vessel containing the volatile oil was placed in the well of the desiccator and several small pots containing larvae were placed in the ordinary level above the well. Before putting these pots inside, the desiccator was allowed to attain the desired temperature by standing in the incubator. Pots (which contained six larvae each) were removed from the incubator at suitable times and not merely were the larvae examined then, but they were preserved, some in the same water and some in clean water, to discover their eventual fate.

The following experiment was done with the top cut of an SO_2 extract of kerosene (Anglo-Iranian Oil Co.), which boiled below 145°C. The pots contained six larvae and two pupae, and the incubator was at 30°C. The times before removal were chosen after a preliminary inspection of the appearance of the larvae. A remarkable feature was the great difference in the susceptibility of *Culex* and *Anopheles* to vapour. In a *Culex* experiment the first pot was removed after three hours and all the larvae were still evidently alive, although in all but one the tracheae were collapsed. The pupae were only feebly alive. The second pot was removed after six hours and showed a similar state of affairs. The third pot was left in for 24 hours, and larvae and pupae were all dead. The pupae in the first two pots remained very feeble and died soon afterwards ; the larvae at first showed signs of recovery, being more lively in their movements, but most of them relapsed again and died without redistending their tracheae. Only one of this dozen made a full recovery and pupated. An extension of this experiment consisted in taking the water which had stood overnight in the desiccator and in which the larvae had died and placing fresh larvae and pupae in it to stand in the open air. In two hours the larvae had collapsed their tracheae and were far from lively, while later on they all died ; the pupae, on the other hand, were not adversely affected, and in due course adults emerged. It was shown that three hours' exposure of the water to vapour did not lead to this effect, which must be due to condensation of some constituent on the water. In the experiment with *Anopheles*, the first pot was removed after half an hour, since it was clear from inspection that the larvae were feeble already. There were no pupae in this experiment. The second pot was removed after 1½ hours and the third after 3 hours. In the last none were alive in the sense of responding to prodding. Owing to the strong pigmentation of *Anopheles* the point of death cannot be determined so clearly as with *Culex*, where gentle waving motion of the tracheae can be clearly distinguished after response to prodding has ceased. The larvae were therefore all preserved and classed as doubtful even if thought dead. Next day most of those in pot 3 were decomposed, so that it was considered that they had been dead on the first examination. Most of the others died off gradually and, as in the *Culex* experiment, only one pupated and emerged.

Experiments have also been done with toluene vapour, in which none of the surviving larvae made a proper recovery but died in a shorter or longer time.

One experiment was done using amyl alcohol vapour. This was done at room temperature (17°C.), and the larvae were still active after 5 hours but gave no reaction to prodding after 8 hours. When examined (they were a set of six) 3 had collapsed tracheae and 3 not, 2 of the former and 1 of the latter showing absolutely no motion internally. Nevertheless after standing in fresh water in the open overnight they all recovered to the extent of showing movement. One of the three with collapsed tracheae died the next day, but one redistended the tracheae. Altogether three of them pupated (whether they emerged was not observed).

In conclusion it is evident that the effect of vapour while frequently fatal is not invariably so. It may be, as Freeborn & Atsatt claim, that physiologically the cause of death in oil film experiments is more frequently due to the effect of vapour, but on the practical side it only needs to be stressed that a penetrating oil will produce a certain kill of larvae, while an oil that has difficulty in penetrating will produce an uncertain kill no matter how powerful its vapour may be.

Toxicity in Relation to Chemical Composition.

Oils have so far been discussed chiefly in relation to their volatility. It is now time to discuss them more from the point of their chemical composition. The most far-reaching investigation along these lines is that of Ramsay & Carpenter (1932) ; it is indeed almost the only one in which proper consideration of the chemistry is made, although most workers are familiar with the bald statement that refined paraffin oils are comparatively non-toxic, while oils with a high proportion of aromatics are fairly rapid in their lethal action. Green (1924) has stated that the most toxic materials are removed in refining, but he did not state what substances he considered them to be.

In the following paragraphs experiments will be described in which have been used : (1) Refined paraffins ; (2) refined paraffins to which were added traces of substances which are, or are similar to substances which are, present in crude petroleum—(*a*) sulphur compounds, (*b*) nitrogen compounds, (*c*) hydroxy- and carboxy-compounds ; (3) mixture of paraffins with hydrocarbons of the aromatic series.*

1. Through the kindness of the Oil Companies interested in this work a number of oils have been available of which the composition in a broad sense was known. Refined paraffins with only a small trace of aromatics were available in boiling ranges from about 150°C. upwards, as follows :—

"Paraffin Kerosene," rigidly purified from aromatics, etc., specially supplied by Burmah Oil Co. B.R. 150°–280°C.

"Grangemouth Kerosene (Kerosene F)," approximately 98 per cent. paraffin, almost but not entirely free from sulphur compounds, manufactured by Scottish Oils, Ltd. B.R. 190°–280°C.

"White Oil" and "Shell Transformer Oil" (Shell Co.), high boiling paraffin preparations. The former has I.B.P. 288°, 70 per cent. distils to 358°C.

The products were further fractionated by distillation.

It has been confirmed that these oils are feeble in their killing power. Indeed it is probable that they have no actual toxic effect but kill merely by preventing the air supply. There is a good deal of variation in the time of survival after treatment with these oils which cannot be ascribed to the effect of too small doses, since the larvae generally remain at the surface (often being caught in it full length) until their tracheae are fully distended with oil. That their action is one of suffocation is supported by experiments in which the oiled larvae were exposed to different temperatures. If the larvae are dependent on oxygen dissolved in the water, this can be diminished by raising the temperature, which will have the additional effect of raising the metabolic demand for oxygen too. A steep drop in the survival time with rise of temperature might be expected therefore, and this in fact does definitely occur. Scottish Oils Ltd. " Grangemouth " Kerosene (" Kerosene F ") boiling 190°–280°C. forms a very good material for this experiment as it oils the larvae very readily. Batches of 16 oiled larvae were put in water and stored at various temperatures, with the following results :—

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* In this work no distinction has been made between paraffins and naphthenes, as they are equally inert towards larvae. The pure "Paraffin Kerosene" of Burmah Oil Co. was exclusively paraffin ; in the other preparations the term "paraffin" is to be interpreted as "paraffin + naphthene."

30°C.—All larvae dead overnight ; several black and decomposing.

27°C.—All but one dead overnight ; survivor lived till third morning.

21°C.—Three dead overnight, 10 during next 24 hours, 3 survivors living 7, 7 and 10 days respectively.

18°–14°C. (*i.e.* room temperature).—About half generally dead in 24 hours, remainder dying at intervals spaced up to 17 days.

14°–9°C. (*i.e.* room temperature at coldest period of the year).—Fewer died in the first 24 hours, sometimes only 1 or 2, but no increase in life of the longer-living ones.

Culex larvae oiled with fresh films of those oils which penetrate well have not been observed to live more than 20 days at any temperature studied.

2. Now crude petroleum contains in addition to the various types of hydrocarbon, some nitrogen and sulphur compounds and some oxygen-containing derivatives such as phenols and naphthenic acids. These are all present in small concentration. Experiments were carried out in which a substance representative of one of these groups was dissolved in the Scottish Oils Ltd. " Grangemouth " Kerosene in a concentration comparable with that at which it might occur in crude petroleum, so that it could be tested whether it could contribute towards the toxicity at such a concentration.

(*a*) *Sulphur compounds.*

n-butyl mercaptan, *n*-butyl disulphide and thiophenol were used in 1 per cent. concentration. The toxicity of the solution was found to be no greater than that of the kerosene itself. In a parallel experiment it was shown that a 1 per cent. solution of thiophenol in water was fatal to larvae which were placed in it.

(*b*) *Nitrogen compounds.*

Aniline and quinoline were used at 2½ per cent. concentration. No increase in toxicity was observed.

(*c*) *Hydroxy- and carboxy- compounds.*

Phenols and carboxylic acids (naphthenic acids) are present in crude petroleum products. A concentrate of naphthenic acids was supplied by the Shell Co. in the form of a brown, highly viscous liquid. When a little of this was added to " Kerosene F," the spreading power was vastly improved, but there was no notable improvement in toxicity, nearly half the oiled larvae dying in 24 hours, the rest at intervals up to 10 days.

Phenol, on the other hand, proved toxic at a 1 per cent. concentration. The material used was a mixture of phenols as obtained from petroleum from Digboi, Assam (Burmah Oil Co.) ; it was cleaned from tarry matter by steam distillation in the laboratory. None of the larvae oiled with this 1 per cent. mixture survived for as long as 24 hours.

Of the chief types of non-hydrocarbon substances found in petroleum, it therefore appears that only phenol is likely to contribute much to the toxicity in the naturally-occurring concentration. And as toxicity certainly persists after removal of phenols, it must be sought among the hydrocarbons themselves. Aromatic hydrocarbons and their mixtures with paraffin-kerosene were therefore next studied.

3. Aromatic hydrocarbons without exception are highly toxic to larvae, which have a very short survival time if the hydrocarbon has penetrated the tracheae. The wide differences in volatility make difficult a comparison of the relative toxicity of different hydrocarbons in the undiluted state, but certain conclusions can be drawn from experiments with equal-volume mixtures of aromatic hydrocarbon with paraffin (Kerosene F). It is interesting to discover that the most volatile aromatics do not form the most toxic mixtures with kerosene, even when it is certain that the mixture has successfully penetrated the tracheae.

Half-and-half mixtures of " Kerosene F " with various pure aromatic hydrocarbons and with aromatic concentrates have been used. It is fair to add that with some of the volatile aromatics the mixture with kerosene breaks up into lenses very rapidly, so that a proportion of the larvae escape oiling ; they are found oiled only on one side or not oiled at all but merely collapsed. But even taking only those with oil in both tracheae, half-and-half mixtures of paraffin-kerosene with toluene (B.P. 110°C.), pseudocumene (B.P. 169°C.), or a " Light Aromatic Concentrate " from Burmah Oil Co. (B. range 135°–194°C.) did not cause the death of larvae so quickly as a mixture of only one part in five of α-methyl-naphthalene (B.P. 243°C.) in the same kerosene. This mixture oiled all the larvae ; a number lay in the surface and had their tracheae actually distended with oil, these being all dead on the first examination ; those on the bottom had their tracheae collapsed and were mostly alive on the first examination but were dead in less than six hours. It may be deduced that this hydrocarbon has a marked contact-poisoning effect, for its vapour pressure will be negligible in relation to the volatile aromatics.

Another demonstration that a higher-boiling aromatic has a greater toxicity than volatile ones is given by the following experiment with a concentrate of aromatics obtained directly from a petroleum source. An SO_2 extract supplied by Anglo-Iranian Oil Co. of boiling range 130°–280°C. (roughly) possessed the property that when mixed with paraffin kerosene it still gave a film that persisted and did not run to lenses : the 50 : 50 mixture in this case gave rapidly fatal results and all the larvae were dead in 1½ hours. On the other hand, when this SO_2 extract was fractionated and the first 10 per cent. of distillate, boiling below 145°C., was used to make the 50 : 50 mixture with paraffin, the mixture produced was not so toxic, and the numbers dead in 2 hours were 6 out of 16 and 11 out of 16 in two experiments ; in each case some (3 and 2 respectively) lived over 24 hours.

Exactly similar results were obtained with an extract supplied by Burmah Oil Company. " Light Kerosene Extract," B.R. 145°–268°C., 70 per cent. aromatics, on mixing in equal volumes with Kerosene F, gave a mixture which killed all oiled larvae in under 24 hours. But " 25 per cent. Tops of Light Kerosene Extract," B.R. 135°–172°C., 60 per cent. aromatics, mixed in equal volumes with " Kerosene F," gave a result in which 10 out of 32 oiled larvae lived over 24 hours, 5 of them living a whole week.

Still another experiment on these lines was one in which cumene and α-methyl-naphthalene respectively were mixed with an SO_2-treated turbine oil (Anglo-Iranian Oil Co.) of high boiling point and viscosity. The methyl-naphthalene mixture contained only 20 per cent. of the aromatic hydrocarbon, the cumene mixture 50 per cent., but whereas only 1 of 16 larvae survived more than 48 hours in the former, in the latter 11 out of 16 survived that period, 7 survived a week and 2 for 18 days at a winter room temperature, although all were fully oiled.

This experiment incidentally brings out another point, namely that a toxic material can be diluted with non-toxic paraffin without diminishing the activity. By reverse reasoning it is evidently not necessary to effect a concentration of the aromatic constituents in the first place in order to obtain an oil of good toxicity. In fact it is desirable to leave some percentage of paraffin in the oil, for a high percentage of non-volatile aromatics raises the density to near or above that of water, while there are other properties of paraffins which are favourable in a film. Stability is increased, *e.g.* a film of " Spinex " (B.R. 300°–400°C.) becomes broken up in 24 hours but lasts much longer when mixed with " White Oil " (paraffin of same boiling range). Also, as will be presented in the next paragraph, there is a very marked effect of paraffin on the ability of a film to act lethally on pupae.

Some Differences in the Behaviour of Larvae and Pupae towards Oil Films.

Accounts already in the literature differ markedly on the subject of toxicity to pupae ; some authors have said that they are killed with greater ease, others with greater difficulty. Considerable light has fallen on this question in the course of this work. Experiments refer to pupae of *Culex fatigans* unless otherwise stated. The first experiments were carried out with an Edeleanu extract of wide boiling range, 135°–280°C., and the pupae met with a most rapid death. As soon as they hit the film they began to kick out vigorously and soon uncoiled themselves and overbalanced, after which they lay either on their sides or completely upside-down with their trumpets directed downwards. In these positions they speedily ceased to struggle and were rated as dead. The first process took possibly half a minute and death under five minutes. If the film did not cover all the surface, owing either to spreading on a slightly greasy surface or to touching the film after spreading with the fingers or any other greasy object, the pupae would live for varying lengths of time dependent only on how long it was before they hit the film. As soon as they came in contact with it they reacted as described. This was demonstrated over and over again, and the same occurred with such pure hydrocarbons as pseudocumene and para-cymene which boil at 169°C. and 176°C. respectively.

The paraffin " Kerosene F " brought about definite symptoms, but of quite another nature. Most of the pupae capsized themselves in this and lay on their sides but died only after a period measured in hours. With those that did not capsize at once it was noted that when they hit a clear patch of surface after hitting oil the trumpets left two extremely minute drops of oil, showing that the trumpets were " oiled " in the same way as the tracheae of larvae. The general impression obtained was that ensuring the death of pupae was a very easy matter, with aromatics producing a very quick death, paraffins a slow but certain one.

It was later shown that this was an entirely false impression. The first conflicting result was obtained by using a different Edeleanu extract with an I.B.P. of nearly 200°C. (Burmah Oil Co.). Although the pupae were under a continuous film of this oil, it was about 40 minutes before they showed any ill symptoms, during which time they had been touching the surface almost continuously. Later it was shown that with all those oils which have been reported as the most suitable for larvicides, pupae do not perform this kicking out and capsizing but may remain for long periods unharmed. Two of the oils which proved most efficient for oiling larvae, " Gasex " and " SO_2 ext. of Long Time Burning Oil," proved singularly inefficient where pupae were concerned. Under these films pupae behaved as if nothing was there for considerable periods—in one case a pupa was removed after 4 hours under an L.T.B.O. ext. film and placed in clean water, where it successfully emerged a day or so later. Very often the pupae met their death through an inability to maintain themselves at the surface ; apparently they lose air, become heavier than water and fall to the bottom ; after spasmodic attempts to rise they die. Oil is generally not demonstrable in their air-passages after such a death.

The mixture of either of these oils with paraffin (Kerosene F) in equal volumes behaves quite differently. These mixtures were used on a bowl containing both larvae and pupae. After five minutes all the pupae were capsized and kicked out, lying in the surface, and in 1½ hours were all dead, dissection revealing them to be fully oiled both in the trumpets and down the abdominal segments. On the other hand, all the larvae in the two bowls lay on the bottom, having become oiled in the first few minutes.

Higher boiling paraffins do not bring about the effect to such a marked extent, as is shown in a series of experiments in which the products from the Shell Co. were mixed. Films of " Gasex " and of " Gasex "-" Spinex " mixture hardly affected pupae, and when the films broke up clear patches of surface were left and many of the pupae emerged into adults which escaped : 6 out of 11 in the first case, 4 out of 10 in the second, emerged, but they did not all take off successfully. (Actually there is an experimental difficulty—when placed in a small cage it may happen that adults emerge and fly off, but later re-settle and get caught. That this has occurred in experiments is certain from some in which more than one bowl was placed in a cage and adults have been found caught in the film on another bowl. If the adult is not found close to a pupa-case it has been assumed that it made a successful emergence but settled on the water surface later.) Films of " Spinex " mixed with White Oil, or " Gasex "-" Spinex " similarly mixed, also acted only very slowly on pupae. The former (mixed in equal volumes) oiled and killed 2 only out of 10 *Culex* pupae on the day of spreading, 3 more were oiled and killed in course of the next day, and 2 more still a day later ; 3 emerged in the end but were all found caught in the oil which had remained as a more or less continuous film. The other mixture containing equal parts of each of the three components showed even less action ; 10 pupae remained under it overnight without being in any way affected ; 6 of them finally emerged, one of them making a successful escape. All these films were securing the oiling of the tracheae of larvae.

" Malariol " of either formula only seems to oil pupae when very freshly spread. In fresh films of Burmah Malariol they capsize and lie oiled in the surface ; in Assam Malariol they sink to the bottom but are found to be oiled. If the films are as much as one day old they fail to oil the pupae ; those under Assam film fall to the bottom in the same way as described for " Gasex," namely they become heavier than water ; of those under Burmah film some die in this way, but in one experiment 10 out of 16 pupae emerged, though they did not escape from the film.

The above results are all with *Culex* pupae. *Anopheles* pupae are very much more susceptible to the action of oil and perish far more readily. This is attributable to the different shape of their trumpets, which being cut obliquely present a much bigger opening through which oil can hardly fail to enter. Actually no oil tried has failed to penetrate and kill *Anopheles* pupae—films under which *Culex* pupae have stayed unconcerned for hours have oiled *Anopheles* in 10 minutes or so and killed them very soon afterwards.

It is rather difficult to summarise the results obtained with pupae. One conclusion that seems justified is that contact with a film of volatile substance deprives pupae of their power of balance. This perhaps has some relation to the result obtained from the vapour experiments in which pupae were shown to be more susceptible. Even to this there are points of exception to be added. Some experiments were done in which toluene was placed on the surface of a bowl of pupae ; there was intense surface agitation, but after all the toluene was evaporated the pupae were found not all dead—in fact in one experiment 4 out of 8 survived, although no larvae survived the experiment.

Otherwise it must be stated that pupae can survive under circumstances in which larvae are oiled with fatal results with hardly any exceptions. Several times larvae and pupae have been placed under the same film and the larvae have become oiled and died while the pupae have developed successfully (though the adults have not escaped from the film). The contrast between these experiments and those in which pupae have quickly become capsized in the film is very marked and helps to explain the contradictory statements in the literature.

Alterations in the Oiling Properties of Films with Age.

There remains yet to be discussed a side of the investigation in which new and unexpected results have been obtained. It has generally been assumed that it is desirable to employ an oil which remains upon the surface of water for a considerable time. But the question has not been properly faced as to whether films retain their original properties. When any falling-off in toxicity has been observed it has generally been ascribed to the fact that the more volatile constituents, which have always been assumed to be the toxic constituents, have evaporated. Occasionally it has been briefly mentioned that viscosity increases with ageing of the film, and slowness of action has been partially attributable to this (Corbett & Hodgkin).

Ginsburg (1929) referred to the old problem of whether an oil film, so long as it thoroughly covered the surface, would produce a complete kill by suffocation, or whether it must possess "toxic properties." This led him to his interesting penetration experiments, but he seems to have been considering an old film as merely one from which the toxic components had evaporated, for he did not compare the actual penetrating power of fresh and old films. Corbett & Hodgkin found that heavy oil diluted with only one-twelfth of light oil lost activity greatly when exposed for a week, the number dying in an hour falling from round a half to only a few per cent., with similar results for other oils and mixtures.

The observations here to be described began with observing that the time of survival of larvae oiled with films a day or two old was in some cases considerably longer than when oiled with fresh films, and as the water temperatures (in March) did not exceed about 17°C., it seemed unlikely that fractional evaporation should be the cause of it. On examining some of the larvae more closely it was found that they were often not so well oiled, that is to say that oil did not fill the whole length of the main tracheal trunk. Now with fresh films larvae are often found incompletely oiled if they are taken out after fairly short exposure, but they oil up by the creeping motion of the oil afterwards and are later found fully oiled unless the amount that entered is very small indeed. Here, on the other hand, larvae might be found only partly oiled days after exposure and no creeping taking place at all. This, of course, could account for increased survival time—one larva lived at room temperature for 57 days with oil partway up the tracheae, which it is safe to say that it could not have done if oil had penetrated into the whole air spaces. (Incidentally this showed clearly that oil prevents normal development, for though offered food it never developed the pre-pupal characteristics.) Evidently oil does not run along the tracheal lining surface so well after it has been exposed.

Next the short-time exposure experiments were repeated, and it was shown that (with some films) it became possible for the larvae to be under the film for quite considerable times without oil entering the tracheae at all. "Malariol" (Assam formula) shows this very clearly.

Fresh films are known to oil the larvae, with occasional exceptions, in 10 minutes. The following table summarises a series of experiments with older films.

Second day	11	larvae out of	12	oiled in	30	mins.
,,	16	,, ,,	17	,,	20	,,
,,	[6	,, ,,	12	,,	30	,,]
Third day	5	,, ,,	12	,,	30	,,
,,	4	,, ,,	12	,,	30	,,
,,	3	,, ,,	12	,,	30	,,
,,	6	,, ,,	12	,,	50	,,
Fourth day (film used each day)	4	,, ,,	12	,,	30	,,
,, ,, ,,	4	,, ,,	13	,,	30	,,
,, (covered with muslin until day of use)	6	,, ,,	12	,,	35	,,
Sixth day (used every day but one)	no	,, ,,	17	,,	30	,,
	5	,, ,,	17	,,	4	hrs.
	12	,, ,,	17	,,	24	,,
,, (not used between first and sixth)	8	,, ,,	12	,,	30	mins.

Although there are one or two experiments in which the deviation from the average is high, as for instance the one in brackets, it is clear that the penetrating power is deteriorating with the ageing of the film. The experiments in which the film was left undisturbed until the date of use were included because constant dipping in of a pipette to introduce and withdraw larvae results in a great loss of oil which clings to the pipette, and the film becomes progressively thinner. This probably accounts for the great difference between the two sixth-day film experiments.

The thickness of the film does indeed influence the rapidity of the deterioration. A film 35 μ thick did not show much change until the eighth day.

In addition to the above, experiments were done in which the larvae placed under the old film were specially chosen as ones near to pupation. They were then left under the film until either dead or pupated. These results are summarised as follows :—

Seventh day film ...	15 larvae	1 pupated,	14 died (2 in act of pupation).
Eighth ,, ...	11 ,,	5 ,,	6 ,, Pupae died without emerging.
Tenth or later day	11 ,,	7 ,,	all pupae died.
,, ,, ,,	10 ,,	6 ,,	,, ,,
,, ,, ,,	10 ,,	4 ,,	,, ,,
,, ,, ,,	9 ,,	7 ,,	,, ,,
,, ,, ,,	16 ,,	13 ,,	4 pupae emerged, rest died.

An appreciable number therefore always manage to pupate. The fact that the pupae nearly always die appears at first to be a paradox since it has been concluded that pupae oil less readily than larvae, but it has to be remembered that unlimited time was allowed in these experiments. In experiments where lubricating base extract was used to make the film, a larger percentage of the pupated larvae went through to emergence (though rarely escaping from the film).

The cause of this failure of oil to penetrate after long exposure is not known. A film was spread on distilled water to see whether the thickening of the film could be attributed to adsorption of mineral salts at the interface. It was left undisturbed for 10 days and then gently stirred as it was blobby. Of 16 larvae then placed beneath it two only were fully oiled in half an hour and 11 showed no oiling at all, though nearly all showed oil in the tracheae after 6 hours. The behaviour was therefore practically the same as if it had been spread on tap water.

As films which have been spread some time always show a kind of rigidity, some experiments were tried to correlate this with the inability to oil. A very fine steel needle was magnetised (by stroking on a magnet) and was then dropped gently on to a water surface with or without film, where it floated. If placed at an angle to the magnetic meridian it turned round to that position. In a clean water surface it was quite heavily damped and did not oscillate about the meridian at all, going just to it and there stopping in about 5 seconds. Presence of a freshly spread oil film did not affect it, or even possibly lessened the damping, for sometimes a trace of overreaching the mark was noticed, though never a true oscillation. The time for coming to the meridian was the same for two oils which differed widely in the time which they took to spread out over the surface of a circular zinc tray 30 inches in diameter. As the film ages, so the time for the needle to move round to the meridian increases. On a film of "Malariol" (Assam) two days' old the needle took all morning to reach the meridian but got near it in time. On older films of either type of "Malariol" no motion of the needle could be observed. But unfortunately this proved to be no criterion of the oiling capacity of the two films, for the film of Burmah sample oiled the larvae adequately though not completely in a moderate exposure. A film of refined white oil (Shell Transformer Oil) was also followed in this way. Two days after spread the needle took a considerable time to reach the meridian, but on the other hand, all the larvae placed under it were fully oiled in half an hour. On the seventh day from spreading the needle would not move in the surface at all and this time it was true that half an hour was not sufficient time to oil the tracheae of the larvae, only about half being in the oiled state.

This method is not very satisfactory, however, for water alone so very readily develops a scum on which the needle will not turn round (and also on which oil will not spread). An experiment was tried with an oil the film of which contracted to a central patch. In the oil portion the needle took about 20 seconds to reach the meridian, but in the portion of the surface where the oil had receded, and which might be called the uncovered portion of the surface, the needle remained motionless, there being evidently a quite rigid scum over that part.

The change in properties of "Malariol" seems to be dependent on its lying in a thin film on water, for it did not occur with a sample that was allowed to stand as a rather thin layer on a dry glass dish for a week and then poured on to the surface of water. Although the oil seemed to be a little stickier, all of 18 larvae were fully oiled in three-quarters of an hour. This seemed to tell against a possible effect of oxidation or oxidative polymerisation, and another experiment pointed to the same conclusion. In this experiment a slow stream of air was blown through some of the oil for 2½ hours. The air-oil surface was thus quite considerable, as it bubbled up the tube. But when the oil was spread on water in the customary dosage all the larvae (12) were oiled in the half-hour.

At present therefore this phenomenon is not explained. It does not occur with all oils, in fact it is not a factor of much consequence with the other formula of "Malariol," the Burmah formula. It must be pointed out that there are some differences in the spreading properties of these two oils. Both spread completely over the surface unless it is grossly greasy, but on standing differences occur. After standing for say an hour, the Burmah film appears the better, for it remains uniform, while the Assam collects into blobs; but after standing for a whole day or more the reverse is true, for the Assam seems to spread itself out to moderate uniformity, while the Burmah gradually shrinks away from the edges and contracts into a single central patch. For experiments with old films, therefore, the Burmah film has to be gently stirred until it covers all the water surface. Only once has such a re-spread film failed to oil the tracheae of nearly all the larvae in say about an hour, and satisfactory oiling and killing have been obtained up till the twelfth day at least, even when the appearance of the surface has been far from hopeful. The very toxic "SO_2 extract of L.T.B.O." resembles the Burmah brand of "Malariol" in that it remains an excellent spread at first and then contracts into one patch; its oiling properties however deteriorate. It does not last a sufficient number of days to carry the comparison right on with Assam "Malariol." "Gasex" and even "Spinex" cannot be brought into this series at all, as their films break up and disappear in only a day or so, but when mixed with some white oil the film persists and remains covering the whole surface for at least a week. The oiling powers, however, are found to have suffered some deterioration.

From these experiments therefore it appears that obtaining a film of high durability is not after all such a desirable thing. Even though adults rarely make a successful escape, if larvae are developing under the film the cause of control is not being served and it would be preferable to have the surface re-oiled with fresh oil.

Conclusions.

To conclude, this work has done something to show on what points the most emphasis should be laid. Above all it is shown to be desirable to have an oil which readily penetrates the tracheae of larvae. Actual toxicity is a secondary matter, for the presence of oil prevents ordinary development. The best penetrating oils are shown to be of a medium boiling range (with suitable modification for temperature), not involatile enough to be markedly viscous, and not volatile enough to give that immediately irritating effect which causes the larva to collapse its tracheae and dive without receiving a dose of the oil. Other conditions which prevent or hinder normal oiling of the tracheae have also been discussed together with their bearing on the at present accepted views as to what are desirable features for a larvicidal oil. Up to the present no simple test can be applied to decide the efficacy of an oil for these purposes, but a laboratory trial, particularly incorporating an experiment with an old exposed film, will convey the necessary information in a reasonably short time. In the present work, however, to obtain such a test has not been the objective, but rather to answer biological questions as the action which oils have on mosquito larvae.

Finally, I should like to express my thanks to Prof. P. A. Buxton for his help and continued interest in this work.

References.

CORBETT & HODGKIN. (1931). Bull. Inst. Med. Res. F.M.S., no. **5.**

FREEBORN & ATSATT. (1918). J. Econ. Ent., **11,** p. 299.

GINSBURG. (1929). Proc. 16th Ann. Mtg. New Jersey Mosquito Exterm. Assoc., p. 50.

GREEN. (1924). Amer. J. Hyg., **4,** p. 12.

HACKER. (1925). How oil kills Anopheline larvae.—F.M.S. Malaria Bur. Rep. **3.**

HOWARD. (1892). Insect Life, **5,** pp. 12, 109 & 199.

LEESON. (1932). Bull. Ent. Res., **23,** p. 25.

RAMSAY & CARPENTER. (1932). Rec. Malar. Surv. India, **3,** p. 203.

TAKATSUKI. (1917). Kyoto Igaku Zassi, **14,** p. 84.

THE JAMAICAN SPECIES OF *HIPPELATES* AND *OSCINELLA* (DIPTERA, CHLOROPIDAE).*

By Henry W. Kumm, M.D., D.P.H.

(Plate VII.)

In the course of a study undertaken in Jamaica to determine the possible importance of insects as vectors of yaws, many observations were made on the morphology, distribution and habits of the *Hippelates* and *Oscinella* flies of this island. Attention was focused on these flies, because they were the insects which were found in greatest abundance among those feeding on ulcers.

C. C. Gowdey (1926) listed four species of *Hippelates* flies from this island : *H. bicolor*, *H. convexus*, *H. dorsalis* and *H. flavipes*. The fly which he designated as *H. flavipes*, Loew, is the one that we are now calling *H. pallipes*, Loew, after Aldrich (1931). We have been informed by Dr. C. H. Curran that *H. bicolor*, Coquillet, is a synonym of *H. pusio*, Loew. *H. dorsalis*, Loew, has been taken in small numbers in nineteen different localities during the course of the present island survey, but we have been unable to find specimens of *H. convexus*, Loew.

C. C. Gowdey (1926) does not list any species of *Oscinella* (*Botanobia*) from Jamaica. We have taken two, namely *Oscinella mars*, Curran, and *O. tripunctata*, Curran, the former being quite common and widely distributed. It is likely that other Jamaican species of *Oscinella* have been missed during the course of the present survey, because our whole attention was concentrated on flies which fed on ulcers or wounds. Curran (1928) reported no less than sixteen species of *Botanobia* (*Oscinella*) and fifteen of *Hippelates* from Porto Rico and the Virgin Islands. We have taken twelve species of *Hippelates* here, but only two of the genus *Oscinella*. The generic term *Oscinella* will be employed instead of *Botanobia* in the present paper, following the usage of Curran (1931).

Relative Prevalence of the different Species.

In a period of approximately 20 months, during which this study was carried out, 1,178 fly catches were made and 186,084 Chloropidae were taken ; 93·7 per cent. of these were flies caught with live animals as bait, that is, using ulcers on human beings, donkeys or dogs, while 6·3 per cent. of the flies were taken in traps baited with decaying dead animal matter.

There was a marked difference in the relative prevalence of the various species according to whether live or dead bait was used. Traps were made in conformity with the directions given by Parman (1932), but of somewhat smaller size than his. Various baits were used in these traps, such as the mixture recommended by Parman (1932), namely one pound of beef liver and two ounces of urea to four gallons of water. Other trap baits included decaying beef blood or lean meat in water, with or without urea. Decaying oranges, tomatoes, or human faeces did not attract any Chloropidae ; but most of the combinations of decaying dead animal tissues that were tried were satisfactory for *H. peruanus*, Becker. The comparative prevalence of the species taken with live animals as bait, or in traps containing decaying dead animal matter, is shown in Table I.

In certain studies of the seasonal and hourly variations in the fly catch, as well the effects of wind, temperature, and relative humidity upon fly activity, we used donkeys with chronic leg ulcers as bait. The donkeys became quite tame, as they

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* The studies and observations on which this paper is based were conducted with the support and under the auspices of the International Health Division of the Rockefeller Foundation. From the laboratory of the Jamaica Yaws Commission.

TABLE I.

Comparative Prevalence of the various Species of Hippelates *and* Oscinella *Flies as caught with a Live Animal as Bait, or with Dead Decaying Animal Matter in Traps.*

Species of Fly	Flies caught with live animal bait : donkeys, dogs, or humans		Flies caught in traps baited with decaying dead animal matter	
	Numbers	Per cent.	Numbers	Per cent.
Hippelates pallipes, Loew	142,364	81·65	322	2·75
Hippelates currani, Aldrich	13,756	7·89	750	6·40
Hippelates peruanus, Becker	3,455	1·98	8,072	68·88
Hippelates pusio, Loew	8,038	4·61	1,416	12·08
Hippelates illicis, Curran	2,452	1·41	332	2·83
Oscinella mars, Curran	3,232	1·85	611	5·21
Oscinella tripunctata, Curran	91	0·05	119	1·02
Hippelates flaviceps, Loew	374	0·22	9	0·08
Hippelates tibialis, Duda	247	0·14	4	0·03
Hippelates proboscideus, Williston ...	124	0·07	79	0·67
Hippelates turneri, Kumm	100	0·06	1	0·01
Hippelates nobilis, Loew	87	0·05	—	—
Hippelates dorsalis, Loew	42	0·02	3	0·03
Hippelates saundersi, Kumm	3	—	—	—
Prohippelates pallidus, Loew	—	—	1	0·01
Total	174,365	100·00	11,719	100·00

were used for this purpose for about a year and a half. But since yaws is a human disease, and not known to occur naturally in the lower animals, we felt that in making the fly survey of the island, our greatest interest lay in flies which fed on ulcers on human beings. Therefore, in the actual survey, a boy with a chronic ulcer on his left shin was taken from place to place and used as bait. A routine was established of making all catches for exactly fifteen minutes in order to obtain quantitative as well as qualitative data. Simultaneous wind velocity readings were taken before and after each catch, so as to decide whether the catch was satisfactory, for it had been found by Kumm (1934) that wind velocities of 300 feet per minute or more inhibited fly activity to a great extent.

The barometric pressure was read with an aneroid at each place where sample fly catches were made, and the elevation above sea-level was calculated. In all, 284 localities were visited in the island. The relative prevalence of the *Hippelates* and *Oscinella* flies which were taken has been tabulated by the number of localities in which each species was found. A comparison of Tables I and II shows that not only did *H. pallipes* provide the largest number of flies caught with live animal bait, but also that this species was found in the greatest number of the localities visited. *H. currani*, Aldrich, came second in both tabulations.

TABLE II.

Number of Localities in Jamaica in which the various Species of Hippelates *and* Oscinella *Flies were caught.*

Species of Fly	Number of localities in which species was taken	Percentage of the the total number of localities surveyed
Hippelates pallipes, Loew	278	97·9
Hippelates currani, Aldrich	195	68·7
Hippelates peruanus, Becker	115	40·5
Hippelates pusio, Loew	106	37·3
Hippelates illicis, Curran	146	51·4
Oscinella mars, Curran	179	63·0
Oscinella tripunctata, Curran	27	9·5
Hippelates flaviceps, Loew	78	27·5
Hippelates tibialis, Duda	25	8·8
Hippelates proboscideus, Williston ...	38	13·4
Hippelates turneri, Kumm	32	11·3
Hippelates nobilis, Loew	14	4·9
Hippelates dorsalis, Loew	19	6·7
Hippelates saundersi, Kumm	3	1·1
Prohippelates pallidus, Loew	1	0·4

Effect of Elevation upon certain Species of Flies.

An analysis was made of the relative prevalence of the six commoner species at different elevations above sea-level. The results are given in Tables III, IV and V and in fig. 1. It is evident from the tables that *H. pallipes*, Loew, was taken in greatest numbers at elevations varying between 101 feet and 1,500 feet above the sea. The maximum catch of *H. pallipes* was made at Grantham in the parish of Clarendon, where 1,668 flies of this species were captured in 15 minutes on yaws lesions on patients. The elevation of Grantham is 1,040 feet. Incidentally, it may be mentioned that three-quarters of the children in the 10 to 14 year age group at Grantham were infected with yaws, as determined by the Yaws Commission's survey of that area. *H. pallipes* was rare at sea-level, and relatively infrequent at elevations above 2,000 feet.

H. currani, Aldrich, attained its maximum density in the zone from 101 to 500 feet elevation, that is, somewhat lower than *H. pallipes*. But the elevation curve of *H. currani* was similar in other respects to that of *H. pallipes*. The peak catch of *H. currani* was made at Papine in the parish of St. Andrew.

H. pusio, Loew, and *H. illicis*, Curran, were both found near the seashore, and hence showed an entirely different type of curve. The largest catches of *H. pusio* were made in the hot alluvial plains of lower St. Catherine and Clarendon. *H. illicis* was very prevalent in Kingston, at Alligator Pond in Manchester, and also at St. Ann's Bay and Ocho Rios in the parish of St. Ann, all of which places are at sea-level. It is interesting to note that *H. pallipes* is practically unknown in Kingston, for this species represented only 2 per cent. of all flies taken at the Yaws Commission Laboratory. *H. illicis* was present in small numbers at the higher elevations, but *H. pusio* practically disappeared above 1,000 feet.

H. peruanus, Becker, was often found above an elevation of 2,000 feet, and so too was *Oscinella mars*, Curran. But any significance that might attach to a slight similarity between the elevation prevalence curves of *H. peruanus* and *H. pallipes* was counterbalanced by the fact that *H. peruanus* fed but rarely on ulcers or yaws lesions. The figures for *H. peruanus* were calculated from the catches made with live animal bait only ; the 8,072 flies of this species caught in traps were disregarded in Table V. Although a few *Oscinella mars* were found in no less than 179 localities in Jamaica, this fly was not caught in great numbers anywhere.

TABLE III.

The Influence of the Elevation above Sea-Level upon the Prevalence of Hippelates pallipes *and* Hippelates currani.

Elevation above sea-level in feet	*Hippelates pallipes*			*Hippelates currani*		
	Number of localities surveyed in this group	Average catch of *Hippelates pallipes* per man per hour	Percentage of all flies taken in this group represented by *Hippelates pallipes*	Number of localities surveyed in this group	Average catch of *Hippelates currani* per man per hour	Percentage of all flies taken in this group represented by *Hippelates currani*
0 to 100	56	188·0	46·1	54	53·3	12·4
101 to 500	66	505·1	76·1	55	95·5	13·0
501 to 1,000	65	572·2	81·0	46	78·2	8·5
1,001 to 1,500 ...	44	453·2	83·7	25	32·6	4·5
1,501 to 2,000	32	275·3	88·7	12	20·0	3·1
More than 2,000 ...	15	197·1	66·6	3	9·0	4·0

TABLE IV.

The Influence of the Elevation above Sea-Level upon the Prevalence of Hippelates pusio and Hippelates illicis.

Elevation above sea-level in feet	*Hippelates pusio*			*Hippelates illicis*		
	Number of localities surveyed in this group	Average catch of *Hippelates pusio* per man per hour per locality	Percentage of all flies taken in this group represented by *Hippelates pusio*	Number of localities surveyed in this group	Average catch of *Hippelates illicis* per man per hour	Percentage of all flies taken in this group represented by *Hippelates illicis*
0 to 100	28	217·1	30·4	44	57·8	14·0
101 to 500	33	53·3	5·2	38	19·6	2·3
501 to 1,000	26	63·5	5·5	37	22·4	3·3
More than 1,000 ...	18	6·0	0·5	28	20·4	3·3

TABLE V.

The Influence of the Elevation above Sea-Level upon the Prevalence of Oscinella mars *and* Hippelates peruanus

Elevation above sea-level in feet	*Oscinella mars*			*Hippelates peruanus*		
	Number of localities surveyed in this group	Average catch of *Oscinella mars* per man per hour	Percentage of all flies taken in this group represented by *Oscinella mars*	Number of localities surveyed in this group	Average catch of *Hippelates peruanus* per man per hour	Percentage of all flies taken in this group represented by *Hippelates peruanus*
0 to 100	24	16·3	2·5	20	24·4	3·2
101 to 500	43	28·0	3·6	25	41·9	3·9
501 to 1,000	47	30·3	3·2	30	30·0	2·6
1,001 to 1,500	32	28·3	4·9	21	27·2	2·5
1,501 to 2,000	22	21·1	5·2	10	21·6	3·5
More than 2,000 ...	10	28·4	8·9	9	96·0	22·5

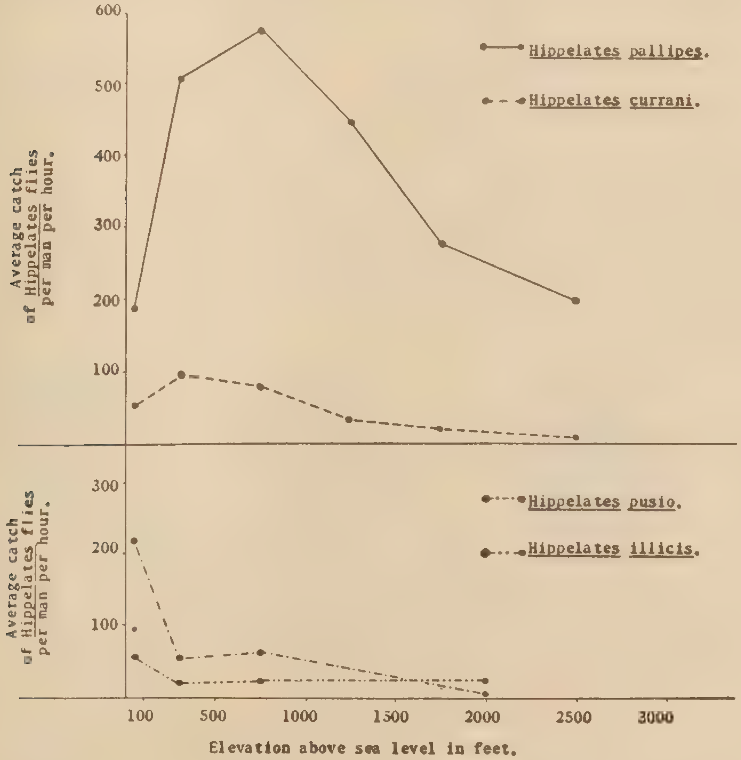


Fig. 1. The relative prevalence of four species of *Hippelates* flies at various elevations above sea-level.

Important Differentiating Characteristics of the Jamaican Chloropidae.

A key has been prepared to facilitate the identification of the fifteen species of flies that have been found feeding on ulcers in Jamaica, and five explanatory figures have been drawn to go with this key. In order to simplify matters the two species of *Oscinella* and one *Prohippelates* are included in the same key with the twelve *Hippelates*.

H. flaviceps, Loew, is separated from the other flies with black mesonata on the fact that its mesonotum is practically devoid of hairs except for three poorly developed rows. This distinguishing feature is brought out in fig. 2. *H. pallipes* has three single rows of hairs between the closely approximated double dorso-lateral rows, making seven distinct rows in all.

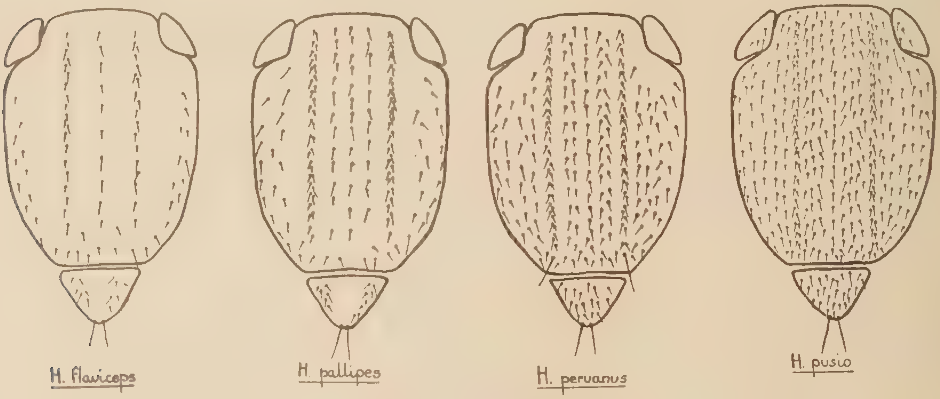


Fig. 2. Mesonota.

H. peruanus, Becker, is distinguished from *H. pallipes* in the key by the width and colour of the genae or cheeks, as well as by the number of rows of mesonotal hairs. The differential characteristics of the genae are indicated in fig. 3. In *H. pallipes* the cheeks are narrow and yellowish anteriorly, but black behind. In *H. peruanus* they are broad and yellow throughout. In *H. pusio* they are dark brown or black.

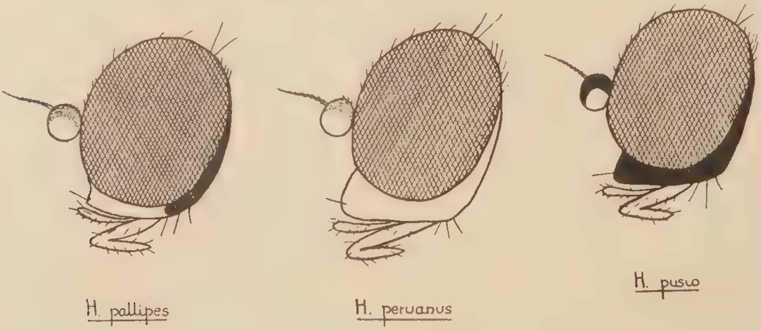


Fig. 3. Genae.

H. pusio, *H. illicis*, *H. currani*, and *H. tibialis*, are differentiated one from another on a basis of the banding of the hind legs. These characters are brought out in fig. 4. The length of the tibial spur is indicated in that diagram also. The brown band on the posterior tibia of *H. currani*, Aldrich, is often quite pale, but the brown coloration of the last two tarsal segments is definite enough. *H. tibialis*, Duda, has very dark bands on the posterior tibiae, and the last four tarsal segments are black. There may be considerable variation in the width of the dark bands on the posterior femora and tibiae of *H. illicis*, Curran, but the apical zones always show at least some banding.

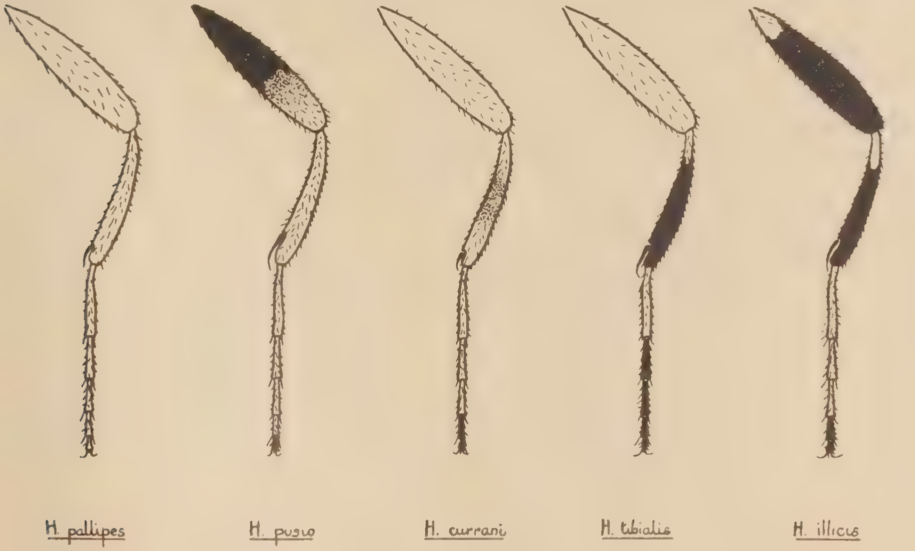


Fig. 4. Hind legs.

No less than seven species of flies have pollinose mesonota. In two of them the pleurae are light yellow in colour and in five this area is brown or black. Of the flies with brownish or black pleurae, two species can be distinguished by the absence of the tibial spur. These are the two *Oscinella* flies, *O. mars* and *O. tripunctata*. The other three species all have large and prominent tibial spurs and can be differentiated most readily by an examination of the triangles on the vertex of their heads. Fig. 5 was drawn to demonstrate that in *H. turneri*, n. sp., the vertical triangle is wholly pollinose, except for an occasional insect, in which there are small bare areas lateral to the posterior ocelli. *H. nobilis*, Loew, has distinct semilunar bare areas constantly

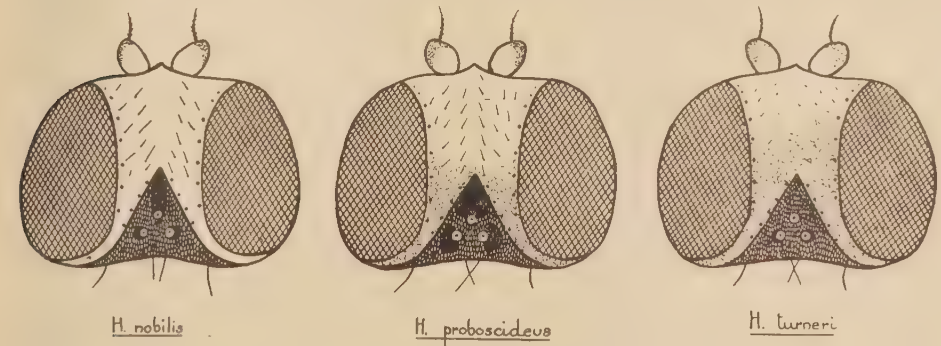
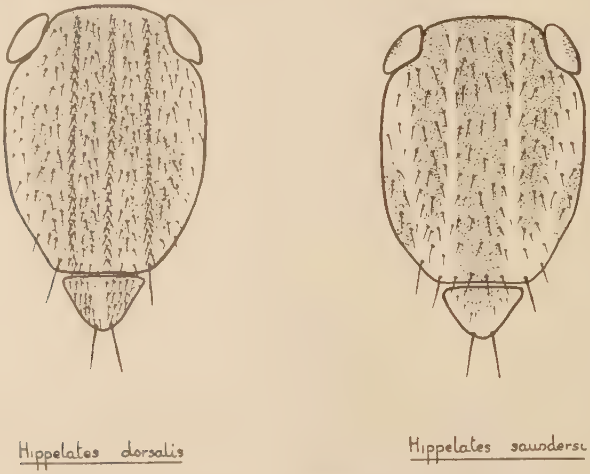


Fig. 5. Vertical triangles.

present lateral to each of the posterior ocelli. This fly also exhibits a fusiform shiny black area which includes the anterior ocellus and extends to the apex of the vertical triangle. *H. proboscideus*, Williston, has a large bare area somewhat resembling an inverted ace of spades, which extends forward from the median ocellus. There are in addition irregularly-shaped bare areas lateral to the two posterior ocelli in this fly. It is not easy to describe the differential features of the vertical triangles, but a glance at fig. 5 should settle any doubtful points. The frontal area between the eyes, and anterior and lateral to the vertical triangle, is yellow in *H. nobilis* and brownish in *H. proboscideus* and *H. turneri*.

The two flies with light yellow-coloured pleurae are quite distinct. The striped basal coloration of the mesonotum of *H. saundersi*, n. sp., is indicated in fig. 6 and separates this species from *H. dorsalis*, Loew. Also the differences in arrangement of mesonotal hairs are evident in that diagram.



Hippelates dorsalis

Hippelates saundersi

Fig. 6. Mesonota.

Key to the Adults of the Hippelates *and* Oscinella *Flies found in Jamaica.*

1.—Mesonotum covered with grey, silvery, or golden dusting..........................9
Mesonotum with a shiny surface devoid of dusting, and either black or brown...2

2.—Mesonotum brown, scutellum pale.....................*Prohippelates pallidus*, Loew
Mesonotum black ; scutellum black..3

3.—Mesonotum practically devoid of hairs except for three rows.......................
Hippelates flaviceps, Loew
Mesonotum with seven or more rows of hairs..4

4.—Femora and tibiae of hind legs entirely yellow.....................................5
Either femora or tibiae or both of them brown or black...........................6

5.—Cheeks broad and yellow ; many rows of hairs on mesonotum....................
H. peruanus, Becker
Cheeks narrow and silvered ; seven rows of hairs on centre of mesonotum......
H. pallipes, Loew

6.—Hind tibiae unbanded but hind femora at least partly brown...*H. pusio*, Loew
Hind tibiae banded..7

7.—Hind femora, tibiae and tarsi all banded..........................*H. illicis*, Curran
Hind tibiae and tarsi banded but femora yellow.......................................8

8.—Last two hind tarsi banded..*H. currani*, Aldrich
Last four hind tarsi banded..*H. tibialis*, Duda

9.—Hind tibiae with a hook-like spine..10
Hind tibiae without such a spine..14

10.—Pleurae yellow..11
Pleurae brownish black with silvery or golden dusting..12

11.—Basal coloration of mesonotum uniformly dark grey............*H. dorsalis*, Loew
Basal coloration of mesonotum arranged in three dark and two light longitudinal stripes..*H. saundersi*, n. sp.

12.—Vertical triangle wholly pollinose..*H. turneri*, n. sp.
Vertical triangle containing some shiny black bare areas and the remainder pollinose..13

13.—Vertical triangle with three shiny black spots; spur on hind tibia inserted at end..*H. proboscideus*, Williston
Vertical triangle with a shiny black fusiform area running forward from the median ocellus; spur on hind tibia arises considerably before the end.........
H. nobilis, Loew

14.—Pleurae wholly pollinose..*Oscinella mars*, Curran
Pleurae polished below..*O. tripunctata*, Curran

Geographical Distribution in Jamaica of the Species captured, with Notes on Nomenclature.

Hippelates pallipes, Loew.

Oscinis pallipes, Loew, Cent. iii, no. 69, p. 39, 1863.
Hippelates flavipes, Loew, Cent. vi, no. 95, 1866; Aldrich, Smith. Misc. Coll. xlvi, p. 635, 1905.
Oscinis pallipes, Aldrich, ibid., p. 639, 1905; Nicholls, Bull. Ent. Res., iii, p. 86, 1912.
Hippelates partitus, Becker, Annales Mus. Nat. Hung., x, p. 89, 1912; Curran, Scientific Survey of Porto Rico and the Virgin Islands, xi, pt. 1, p. 48, 1928.
Hippelates flavipes, Curran, ibid., p. 49, 1928; Graham-Smith, Parasitology, xxii, pp. 466, 1930; Wilson & Mathis, Jour. Am. Med. Ass., xciv, p. 1289, 1930.
Hippelates angustibucca, Duda, Folia Zool. Hydrobiol., ii, 1930.
Hippelates pallipes, Aldrich, Proc. Ent. Soc. Wash., xxxiii, no. 4, p. 70, 1931.

The commonest Jamaican species of *Hippelates* is mentioned in the literature under at least five different names, but in the present report we have used the one which was designated as correct by Aldrich in 1931. Cottam (1923) described a new species of Chloropid fly from Khartoum in the Anglo-Egyptian Sudan, under the name of *Oscinis pallipes*. But by a strict application of the rules of nomenclature this fly would need a new name, since *Oscinis pallipes*, Cottam 1923, is preoccupied by *Oscinis pallipes*, Loew 1863.

Males of *H. pallipes* can readily be distinguished from females by their smaller size, rounded end of the abdomen, vertical triangle yellow at the apex, and pale yellow coloration of the third antennal joint. Some of these differences led to Becker's mistake in 1912, when he gave to males of this species the name *H. partitus*. Occasionally we have seen female *H. pallipes* with some or all of their legs reddish brown, but this is comparatively rare and purely an artefact.

The localities in Jamaica where *H. pallipes* have been captured are given in the following list. It should be pointed out that the large majority of the catches made in Jamaica were in the six parishes of St. Andrew, St. Ann, St. Catherine, St. Mary, St. Thomas, and Portland ; fewer localities were visited in the Western portion of the island.

Parish.	*Localities.*
Clarendon	Alley, Chapelton, Croft's Hill, Four Paths, Grantham, Hayes, Kellits, Pedro River, Turner's Four Paths.
Hanover	Cascade, Kendal, Miles Town.
Kingston	Kingston, Smith Village.
Manchester	Alligator Pond, Cedar Grove, Devon, Mile Gully, Newport, Porus, Shooter's Hill, Williamsfield.
Portland	Balcarres, Belvedere, Berwick, Birnamwood, Black Hill, Bybrook, Castle Comfort, Cedar Valley, Craig Mill, Darley, Ecclesdown, Fairy Hill, Fellowship, Fruitful Vale, Hope Bay, Manchioneal, Millbank, Moore Town, Mount Oakley, Mount Pleasant, Nonsuch, Orange Bay, Panton's Hope, Plum Valley, Port Antonio, Rio Grande, Sherwood Forest, Silver Hill Bridge, Skibo, Spring Hill, Swift River, Windsor Castle, Windsor Forest.
St. Andrew	August Town, Blake Bridge, Brandon Hill, Bull Bay, Cane River Falls, Cherry Gardens, Clifton, Constant Spring, Cooper's Ridge, Golden Spring, Gordon Town, Greenwich, Guava Ridge, Half Way Tree, Hardware Gap, Hermitage Dam, Irish Town, Lawrence Tavern, Mannings Hill, Maryland, Mavis Bank, Mount Airy, Mount Charles, Mount James, Mount Pleasant, Newcastle, Papine, Red Hill, Rockfort, Silver Hill Gap, St. Christopher's, St. Peter's, Stony Hill, Three Miles, Tom's River, Waddell's Mountain, Zion Hill.
St. Ann	Alderton, Alexandria, Alva, Bamboo, Bensonton, Blackstonedge, Breadnut Hill, Britton Ville, Brown's Town, Chalky Hill, Claremont, Colegate, Coultart Grove, Davis Town, Dry Harbour, Epworth, Fargos, Gibraltar, Gloucester Hall, Golden Grove, Good Design, Goshen, Hampstead, Laughlands, Lodge, Mammee Bay, Moneague, Mount Olivet, Ocho Rios, Parry Town, Pedro, Philadelphia, Prickley Pole, Retirement, River Head, Runaway Bay, St. Ann's Bay, St. Faith, St. John's, Stepney, Sturge's Town, Tracy Town, Walker's Wood, White River.
St. Catherine	Bamboo Market, Bannister Hall, Bartons, Belfield, Benbow, Bog Walk, Braeton, Brown's Hall, Bushy Park, Caymanas, Charlemont, Crawle, Ewarton, Glengoffe, Gregory Park, Harewood, Hartlands, Head Works, Hyde, Linstead, Lluidas Vale, Mountain River, Mount Rosser, Old Harbour, Orange Field, Pear Tree Grove, Point Hill, Pot House Pen, Redwood, Rio Magno, Riversdale, Salt Pond Pen, Spanish Town, St. John's Road, Troja, Tulloch, Twickenham Park, Windsor Park.
St. Elizabeth	Elderslie, Leeds, Lititz, Maggotty, Middle Quarters, Malvern.
St. James	Amity Hall, Lilliput, Roehampton, Salt Spring, Stonehenge.
St. Mary	Annotto Bay, Belfield, Brainerd, Broadgate, Camberwell, Castlemine, Castleton, Clermont, Clonmel, Dreseke, Elliott, Enfield, Fontabelle, Gayle, Golden Valley, Goshen, Guy's Hill,

	Halifax, Hampstead, Herman Hall, Highgate, Islington, Iterboreale, Labyrinth, Lucky Hill, New Ramble, Oracabessa, Pembroke Hall, Platfield, Port Maria, Quebec, Retreat, Richard's Pen, Richmond, Robin's Bay, Rock River, Salt Gut, Sandside, Scott's Hall, Spring Valley, Water Valley, Windsor Castle.
St. Thomas	Aeolus Valley, Airy Castle, Albion, Amity Hall, Arcadia, Arntully, Bachelor's Hall, Bath, Beacon Hill, Bowden, Cedar Valley, Dalvey, Easington, Eleven Miles, Hampton Court, Hector's River, Hillside, Llandewey, Leith Hall, Morant Bay, Mount Lebanus, New Monklands, New Pera, Old Pera, Orange Park, Pear Tree River, Pilot, Port Morant, Red Hills, Richmond Vale, Rocky Point, Seaforth, Serge Island, Soho, Somerset, Stokes Hall, Style Hut, Sunning Hill, Trinity Ville, White Hall, White Horses, Windsor Forest, Yallahs.
Trelawny	Carey Park, Clark's Town, Duan Vale, Good Hope, Troy.
Westmoreland	Grange, Lincoln, Petersfield.

Hippelates currani, Aldrich.

Hippelates currani, Aldrich, Proc. Ent. Soc. Wash., xxxiii, no. 4, p. 70, 1931.
Hippelates collusor, Curran, Am. Mus. Nov. no. 220, p. 4, 1926.
Hippelates bicolor, Curran, Scientific Survey of Porto Rico and the Virgin Islands, xi, pt. 1, p. 49, 1928.
Hippelates collusor, Curran, ibid., 1928.

H. currani, Aldrich, was described by Curran (1926) under the name of *H. collusor*. But Aldrich (1931) pointed out that in 1895 Townsend gave the name *Oscinis collusor* to a fly from lower California, which was almost certainly some sort of *Hippelates*. Therefore Aldrich proposed the name *H. currani* to supersede *H. collusor*, Curran.

The brown band on the posterior tibia of this fly is sometimes very pale, but the tarsi of the fore legs and the last two tarsal segments of the hind legs are always brown. The third antennal joint of males of *H. currani* is entirely yellow, whereas in females it is brown above. The names of the localities where *H. currani* have been found are given below.

Parish.	*Localities.*
Clarendon	Alley, Chapelton, Crofts Hill, Four Paths, Grantham, Hayes, Kellits, Pedro River, Turner's Four Paths.
Hanover	Cascade, Kendal, Miles Town.
Kingston	Kingston, Smith Village.
Manchester	Alligator Pond, Mile Gully, Porus, Shooter's Hill, Williamsfield.
Portland	Balcarres, Belvedere, Berwick, Black Hill, Bybrook, Buff Bay, Castle Comfort, Fairy Hill, Fruitful Vale, Hope Bay, Manchioneal, Mount Pleasant, Orange Bay, Panton's Hope, Plum Valley, Port Antonio, Rio Grande, Sherwood Forest, Silver Hill Bridge, Skibo, Swift River, Windsor Castle, Windsor Forest.
St. Andrew	August Town, Blake Bridge, Bull Bay, Cane River Falls, Cherry Gardens, Clifton, Constant Spring, Cooper's Ridge, Golden Spring, Gordon Town, Half Way Tree, Lawrence Tavern, Maryland, Mount Charles, Mount Pleasant, Papine, Rockfort, Three Miles, Tom's River, Waddell's Mountain, Zion Hill.

St. Ann	...	Alderton, Alva, Brown's Town, Chalky Hill, Claremont, Coultart Grove, Dry Harbour, Hampstead, Laughlands, Lodge, Mammee Bay, Moneague, Ocho Rios, Philadelphia, Runaway Bay, St. Ann's Bay, Stepney, Sturge's Town, Walker's Wood, White River.
St. Catherine	...	Bamboo Market, Bannister Hall, Bartons, Belfield, Benbow, Bog Walk, Braeton, Bushy Park, Caymanas, Charlemont, Crawle, Ewarton, Glengoffe, Great Salt Pond, Gregory Park, Harewood, Hartlands, Head Works, Hyde, Linstead, Lluidas Vale, Mountain River, Mount Rosser, Old Harbour, Old Harbour Bay, Orange Field, Pear Tree Grove, Pot House Pen, Redwood, Rio Magno, Riversdale, St. John's Road, Salt Pond Pen, Spanish Town, Troja, Twickenham Park, Windsor Park.
St. Elizabeth	...	Leeds, Lititz, Maggotty, Malvern, Middle Quarters.
St. James	...	Amity Hall, Lilliput, Roehampton, Salt Spring, Stonehenge.
St. Mary	...	Annotto Bay, Brainerd, Castleton, Clermont, Dreseke, Enfield, Fontabelle, Gayle, Hampstead, Herman Hill, Oracabessa, Pembroke Hall, Platfield, Port Maria, Richard's Pen, Richmond, Robin's Bay, Rock River, Salt Gut, Spring Valley.
St. Thomas	...	Aeolus Valley, Airy Castle, Albion, Amity Hall, Arcadia, Arntully, Bath, Beacon Hill, Bowden, Cedar Valley, Dalvey, Easington, Eleven Miles, Hampton Court, Hector's River, Hillside, Llandewey, Morant Bay, Mount Lebanus, New Monkland, New Pera, Old Pera, Orange Park, Pear Tree River, Port Morant, Richmond Vale, Rocky Point, Seaforth, Serge Island, Soho, Somerset, Stoke's Hall, Style Hut, Sunning Hill, Trinity Ville, White Hall, White Horses, Yallahs.
Trelawny	...	Carey Park, Clark's Town, Duan Vale, Good Hope.
Westmoreland	...	Grange, Lincoln, Petersfield.

Hippelates peruanus, Becker.

Hippelates peruanus, Becker, Annales Mus. Nat. Hung., x, p. 170, 1912.
Siphonella circumdata, Becker, ibid., p. 185.

Female specimens of *H. currani* with very pale tibial and tarsal banding are sometimes confused with *H. peruanus*. But the habits of the flies are strikingly different; decaying meat as a bait has a pronounced attraction for *H. peruanus*, whereas *H. currani* prefer ulcers on living persons or animals. Males of *H. peruanus* can be distinguished readily from females. Males have a distinctly banded yellow and brown abdomen. The abdomen of females is usually uniformly brown or black. The third antennal joint in males is entirely yellow, whereas in females it is partly brown. *H. peruanus* have been taken in the following 115 localities in Jamaica.

Parish.		*Localities.*
Clarendon	...	Chapelton, Croft's Hill, Four Paths, Grantham, Hayes, Turner's Four Paths.
Hanover ...	...	Cascade, Kendal.
Kingston	...	Kingston, Smith Village.
Manchester	...	Alligator Pond, Cedar Grove, Devon, New Port, Porus, Williamsfield.

Portland	Balcarres, Birnamwood, Black Hill, Bybrook, Orange Bay, Panton's Hope, Rio Grande, Silver Hill Bridge, Spring Hill, Swift River.
St. Andrew	Brandon Hill, Cane River Falls, Cherry Gardens, Clifton, Constant Spring, Cooper's Ridge, Golden Spring, Gordon Town, Half Way Tree, Hermitage Dam, Lawrence Tavern, Manning's Hill, Maryland, Mavis Bank, Mount Charles, Mount Pleasant, Papine, Red Hills, Rockfort, St. Christophers, St. Peter's, Silver Hill Gap, Stony Hill, Waddell's Mountain.
St. Ann	Alderton, Alva, Brown's Town, Dry Harbour, Gloucester Hall, Hampstead, Mammee Bay, Retirement, Runaway Bay, St. Ann's Bay, Stepney, Sturge's Town, Walker's Wood.
St. Catherine	Bamboo Market, Bartons, Belfield, Braeton, Bushy Park, Crawle, Glengoffe, Harewood, Head Works, Mount Rosser, Orange Field, Pear Tree Grove, Redwood, Rio Magno, Riversdale, Troja, Twickenham Park, Windsor Park.
St. Elizabeth	Leeds, Malvern, Middle Quarters.
St. James	Amity Hall, Lilliput, Salt Spring, Stonehenge.
St. Mary	Castleton, Clonmel, Guy's Hill, Scott's Hall.
St. Thomas	Aeolus Valley, Arntully, Bath, Cedar Valley, Dalvey, Hector's River, Hillside, Llandewey, Mount Lebanus, New Monklands, Old Pera, Rocky Point, Soho, Somerset, Trinity Ville, White Horses.
Trelawny	Carey Park, Duan Vale, Good Hope, Troy.
Westmoreland	Grange, Lincoln, Petersfield.

Hippelates pusio, Loew.

Hippelates pusio, Loew, Cent. x, no. 87, 1872.
Hippelates bicolor, Coquillett, Proc. U.S.N.M., xxii, 1900.
Hippelates pusio var. *nigribucca* Duda, Folia Zool. Hydrobiol., ii, 1930.
Hippelates pusio var. *flavibucca*, Duda, *ibid*, 1930.

This fly, which is probably a vector of conjunctivitis in the Coachella Valley in California, was first identified in 1926 from that area as *H. flavipes*, Loew. But Herms soon pointed out that the correct name was *H. pusio*. We have no evidence that this fly transmits conjunctivitis in Jamaica, and it probably plays no part whatever in the transmission of yaws either, because it is most plentiful in areas where yaws does not exist. The 106 places where it has been caught are given below.

Parish.	*Localities.*
Clarendon	Alley, Chapelton, Four Paths, Grantham, Hayes, Turner's Four Paths.
Hanover	Cascade, Kendal.
Kingston	Kingston, Smith Village.
Manchester	Alligator Pond, Devon, Mile Gully, Shooter's Hill.
Portland	Buff Bay, Bybrook, Fairy Hill, Hope Bay, Orange Bay, Plum Valley, Windsor Castle.
St. Andrew	Brandon Hill, Bull Bay, Cane River Falls, Cherry Gardens, Clifton, Constant Spring, Cooper's Ridge, Golden Spring, Half Way Tree, Lawrence Tavern, Mount Charles, Mount Pleasant, Papine, St. Christopher's, Three Miles, Zion Hill.

St. Ann	Alderton, Epworth, Laughlands, Mammee Bay, Philadelphia, Retirement, St. Ann's Bay, St. Faith, Stepney.
St. Catherine	Bamboo Market, Bannister Hall, Bartons, Belfield, Bog Walk, Braeton, Bushy Park, Caymanas, Charlemont, Crawle, Great Salt Pond, Gregory Park, Hartlands, Head Works, Hyde, Linstead, Old Harbour, Old Harbour Bay, Orange Field, Pear Tree Grove, Pot House Pen, St. John's Road, Salt Pond Pen, Spanish Town, Twickenham Park, Windsor Park.
St. Elizabeth	Leeds.
St. James	Amity Hall.
St. Mary	Annotto Bay, Belfield, Brainerd, Castleton, Claremont, Elliott, Gayle, Iterboreale, Pembroke Hall, Platfield, Quebec, Richmond, Salt Gut, Scott's Hall, Spring Valley.
St. Thomas	Albion, Bath, Beacon Hill, Dalvey, Easington, Hillside, Llandewey, Red Hills, Richmond Vale, Rocky Point, Seaforth, Soho, Trinity Ville, White Hall.
Trelawny	Clark's Town, Duan Vale, Good Hope.

Hippelates illicis, Curran.

Hippelates illicis, Curran, Am. Mus. Nov. no. 220, p. 4, 1926.

We have not found any outstanding differences between males and females of this species, except that males are as a rule smaller in size and have the tip of the abdomen rounded instead of pointed. *H. illicis* is common near the sea-shore and comparatively rare in the rest of the island. The distribution records for Jamaica are as follows.

Parish.	*Localities.*
Clarendon	Alley, Chapelton, Four Paths, Hayes, Turner's Four Paths.
Hanover	Cascade, Kendal.
Kingston	Kingston, Smith Village.
Manchester	Alligator Pond, Newport, Porus, Williamsfield.
Portland	Belvedere, Berwick, Black Hill, Bybrook, Castle Comfort, Fairy Hill, Hope Bay, Manchioneal, Orange Bay, Panton's Hope, Plum Valley, Port Antonio, Rio Grande, Skibo, Swift River, Windsor Castle, Windsor Forest.
St. Andrew	Bull Bay, Clifton, Constant Spring, Golden Spring, Gordon Town, Half Way Tree, Mannings Hill, Mount Charles, Mount Pleasant, Papine, Rockfort, Three Miles.
St. Ann	Alderton, Breadnut Hill, Brown's Town, Chalky Hill, Claremont, Colegate, Dry Harbour, Epworth, Goshen, Hampstead, Laughlands, Lodge, Mammee Bay, Moneague, Mount Olivet, Ocho Rios, Philadelphia, Runaway Bay, St. Ann's Bay, Sturge's Town, Tracy Town, Walker's Wood, White River.
St. Catherine	Apostle's Battery, Bamboo Market, Bartons, Bog Walk, Bushy Park, Caymanas, Crawle, Ewarton, Great Salt Pond, Gregory Park, Harewood, Head Works, Mountain River, Old Harbour, Old Harbour Bay, Orange Field, Pear Tree Grove, Rio Magno, Riversdale, Spanish Town, Troja.
St. James	Amity Hall, Lilliput, Roehampton, Salt Spring, Stonehenge.

St. Mary	Annotto Bay, Brainerd, Clermont, Dreseke, Enfield, Fontabelle, Gayle, Herman Hill, Highgate, Islington, Iterboreale, Labyrinth, Lucky Hill, New Ramble, Oracabessa, Pembroke Hall, Port Maria, Quebec, Retreat, Richard's Pen, Richmond, Salt Gut, Windsor Castle.
St. Thomas	Aeolus Valley, Airy Castle, Arcadia, Bath, Beacon Hill, Bowden, Dalvey, Hector's River, Hillside, Llandewey, Morant Bay, Mount Lebanus, New Monklands, Old Pera, Pear Tree River, Port Morant, Richmond Vale, Rocky Point, Seaforth, Soho, Stokes Hall, Style Hut, Trinity Ville, White Hall, Yallahs.
Trelawny	Carey Park, Clark's Town, Duan Vale, Good Hope, Troy.
Westmoreland	Grange, Petersfield.

Oscinella mars, Curran.

Botanobia mars, Curran, Am. Mus. Nov., no. 220, p. 10, 1926.

This species was found in 179 localities in Jamaica ; only *Hippelates pallipes* and *H. currani* were taken in a greater number of places. But it was not present in great abundance anywhere. It seems to thrive about as well in the high mountains as near the sea. The distribution records made during the present survey are given below.

Parish.	*Localities.*
Clarendon	Chapelton, Croft's Hill, Four Paths, Grantham, Hayes, Turner's Four Paths.
Hanover	Cascade, Miles Town.
Kingston	Kingston.
Manchester	Alligator Pond, Cedar Grove, Devon, Mile Gully, Porus, Williamsfield.
Portland	Balcarres, Belvedere, Berwick, Birnamwood, Black Hill, Bybrook, Cedar Valley, Craigmill, Barley, Manchioneal, Millbank, Moore Town, Plum Valley, Port Antonio, Silver Hill Bridge, Skibo, Swift Rover.
St. Andrew	August Town, Brandon Hill, Blake Bridge, Bull Bay, Cane River Falls, Cherry Gardens, Clifton, Cooper's Ridge, Golden Spring, Gordon Town, Greenwich, Half Way Tree, Hermitage Dam, Irish Town, Lawrence Tavern, Manning's Hill, Mavis Bank, Mount Charles, Mount James, Mount Pleasant, New Castle, Papine, Red Hills, Rockfort, St. Christopher's, Silver Hill Gap, Tom's River, Waddell's Mountain, Zion Hill.
St. Ann	Alderton, Bamboo, Bensonton, Breadnut Hill, Britton Ville, Brown's Town, Colegate, Coultart Grove, Davis Town, Dry Harbour, Epworth, Fargus, Gibraltar, Golden Grove, Good Design, Goshen, Hampstead, Laughlands, Lodge, Mammee Bay, Moneague, Parry Town, Pedro, Philadelphia, Prickley Pole, Retirement, River Head, St. Faiths, Stepney, Sturge's Town, White River.
St. Catherine	Bamboo Market, Bannister Hall, Bartons, Belfield, Braeton, Bushy Park, Caymanas, Charlemont, Crawle, Ewarton, Glengoffe, Hartlands, Head Works, Hyde, Linstead, Lluidas Vale, Mountain River, Orange Field, Pear Tree Grove, Point Hill, Pot House Pen, Redwood, Rio Magno, Troja, Tulloch, Twickenham Park, Windsor Park.

St. Elizabeth	Leeds, Lititz, Malvern.
St. James	Amity Hall, Lilliput, Roehampton, Salt Spring, Stonehenge.
St. Mary	Belfield, Brainerd, Camberwell, Castlemine, Castleton, Dreseke, Elliott, Golden Valley, Goshen, Guy's Hill, Herman Hill, Port Maria, Richard's Pen, Rock River, Salt Gut, Scott's Hall, Water Valley.
St. Thomas	Aeolus Valley, Airy Castle, Albion, Arcadia, Arntully, Bath, Beacon Hill, Cedar Valley, Dalvey, Easington, Eleven Miles, Hillside, Llandewey, Leith Hall, Mount Lebanus, New Monklands, New Pera, Old Pera, Orange Park, Pilot, Richmond Vale, Seaforth, Serge Island, Soho, Somerset, Style Hut, Sunning Hill, Trinity Ville, White Hall, Windsor Forest.
Trelawny	Carey Park, Clark's Town, Duan Vale, Good Hope.
Westmoreland	Lincoln.

Oscinella tripunctata, Curran.

Botanobia tripunctata, Curran, Am. Mus. Nov., no. 220, p. 10–11, 1926.

O. tripunctata was distinctly rare but slightly more prevalent than the figures in Tables I and II would indicate, because considerable time elapsed before we learned how to distinguish the two species of *Oscinella* flies. The localities from which this species was definitely identified were the following.

Parish.	*Localities.*
Clarendon	Chapelton, Pedro River.
St. Andrew	Cane River Falls, Mount Pleasant, Papine, Three Miles.
St. Ann	Chalky Hill, Fargus, Hampstead, Laughlands, River Head, St. Ann's Bay.
St. Catherine	Bamboo Market, Crawle, Ewarton, Head Works, Pear Tree Grove, Rio Magno, Twickenham Park.
St. James	Roehampton, Salt Spring.
St. Mary	Brainerd, Castlemine, Guy's Hill, Scott's Hall.
Trelawny	Clark's Town, Good Hope.

Hippelates flaviceps, Loew.

Oscinis flaviceps, Loew, Cent. iii, no. 71, 1863.
Hippelates nudifrons, Malloch, Proc. U.S.N.M., xlvi, p. 242, 1913.
Hippelates metallicus, Duda, Folia Zool. Hydrobiol., ii, 1930.

The same criticism in regard to the prevalence of *Oscinella tripunctata* applies to *H. flaviceps*, that is, if we had learnt how to identify this species earlier, its island distribution would have been more extensive. For a long time specimens of *H. flaviceps* were included with *H. peruanus*. But latterly this fly was identified with certainty from the following 78 places.

Parish.	*Localities.*
Clarendon	Chapelton, Kellits.
Hanover	Cascade, Kendal, Miles Town.
Kingston	Kingston, Smith Village.
Manchester	Devon, Mile Gully, New Port, Porus.

Portland ...	Black Hill, Darley, Millbank, Plum Valley, Sherwood Forest, Windsor Forest.
St. Andrew ...	August Town, Cane River Falls, Half Way Tree, Mount Pleasant, Papine.
St. Ann ...	Alderton, Bamboo, Chalky Hill, Claremont, Colegate, Davis Town, Epworth, Fargus, Friendship, Gibraltar, Hampstead, Laughlands, Lodge, Mammee Bay, Ocho Rios, Parry Town, Philadelphia, St. Ann's Bay, St. Faith, St. John's, Stepney, Sturge's Town, Tracy Town, Walker's Wood.
St. Catherine ...	Bartons, Brown's Hall, Charlemont, Crawle, Mountain River, Orange Field, Spanish Town.
St. Elizabeth ...	Lititz, Malvern.
St. James ...	Roehampton, Salt Spring.
St. Mary ...	Brainerd, Camberwell, Clermont, Dreseke, Enfield, Goshen, Halifax, Islington, Pembroke Hall, Spring Valley, Windsor Castle.
St. Thomas ...	Bath, Beacon Hill, Dalvey, Hillside, Orange Park, Seaforth, Soho.
Trelawny ...	Clark's Town.
Westmoreland ...	Grange, Petersfield.

Hippelates tibialis, Duda.

Hippelates tibialis, Duda, Folia Zool. Hydrobiol., ii, p. 46–128, 1930.

Some confusion has arisen with regard to this species because Duda placed all his *H. tibialis* as a synonym of *H. illicis*. But Dr. C. H. Curran writes that Duda actually had two species confused under the name *H. tibialis*. The first *tibialis* on the page must be recognized, and only the second is a synonym of *H. illicis*, Curran. Some specimens of the Jamaican species, which we have identified as *H. tibialis*, were actually sent to Dr. Oswald Duda and he confirmed their identification. The distribution records in this island are given below.

Parish.	*Localities.*
St. Andrew ...	Cane River Falls, Cooper's Ridge, Maryland, Mount Pleasant, Papine, Zion Hill.
St. Catherine ...	Bamboo Market, Crawle, Gregory Park, Head Works, Lluidas Vale, Rio Magno, Riversdale, Spanish Town.
St. Elizabeth ...	Malvern.
St. Mary ...	Dreseke, Pembroke Hall, Scott's Hall.
St. Thomas ...	Bath, Beacon Hill, Hillside, Seaforth, Soho.
Trelawny ...	Good Hope.
Westmoreland ...	Grange.

Hippelates proboscideus, Williston.

Hippelates (*Siphomyia*, n. subg.) *proboscideus*, Williston, Trans. Ent. Soc. Lond. p. 419, 1896.

Goniopsita (*Hippelates*) *bracata*, Duda, Folia Zool. Hydrobiol., ii, p. 73, 1930.

Specimens of this fly were sent to Dr. Duda, and he reported that the females were in many respects similar to but not identical with *H. bracata*. Later Dr. C. H. Curran compared other Jamaican specimens with two of the types of *H. proboscideus*, and found them to be the same. However, Dr. Curran feels that *Goniopsita bracata*, Duda, should be considered as a probable synonym of *H. proboscideus*, Williston. This species has been taken in the following 38 localities.

Parish.	*Localities.*
Hanover	Kendal, Miles Town.
Portland	Belvedere, Black Hill, Plum Valley, Swift River, Windsor Castle.
St. Andrews	Cherry Gardens, Constant Spring, Half Way Tree, Irish Town, Mount Pleasant, Papine, St. Peters.
St. Ann	Alderton, Bamboo, Walker's Wood.
St. Catherine	Braeton, Crawle.
St. Elizabeth	Middle Quarters.
St. James	Amity Hall, Roehampton, Salt Spring, Stonehenge.
St. Mary	Richmond.
St. Thomas	Albion, Amity Hall, Bath, Beacon Hill, Dalvey, Leith Hall, Old Pera, Rocky Point, Soho.
Trelawny	Duan Vale, Good Hope, Troy.
Westmoreland	Petersfield.

Hippelates nobilis, Loew.

Hippelates nobilis, Loew, Cent. iii, no. 67, 1863.

The maximum catch of *H. nobilis* was made at Crawle near Caymanas in the parish of St. Catherine. This fly is not common anywhere but is usually encountered in the same type of country as that preferred by *H. pusio*. Distribution records for *H. nobilis* in Jamaica are given below.

Parish.	*Localities.*
Clarendon	Alley.
Portland	Cedar Valley.
St. Andrew	Mount Pleasant, Papine, Silver Hill Gap, Three Miles.
St. Ann	Laughlands.
St. Catherines	Caymanas, Crawle, Gregory Park, Salt Pond Pen, Twickenham Park, Windsor Park.
St. Mary	Guy's Hill.

Hippelates dorsalis, Loew.

Hippelates dorsalis, Loew, Cent., iii, no. 75, 1863.

Although this was a rare species, occasional specimens were caught in eleven out of the fourteen parishes of the island. The nineteen localities where *H. dorsalis* occurred were the following.

Parish.	*Localities.*
Clarendon	Pedro River, Turner's Four Paths.
Hanover	Cascade.
Manchester	Devon.
St. Andrew	Gordon Town, Mount Pleasant, Papine.

St. Ann ...	St. Ann's Bay, Mammee Bay.
St. Catherine	Braeton.
St. Elizabeth	Elderslie, Malvern.
St. James	Roehampton, Salt Spring.
St. Mary	Iterboreale.
St. Thomas	Llandewey.
Trelawny	Clark's Town, Duan Vale, Good Hope.

Prohippelates pallidus, Loew.

Hippelates pallidus, Loew, Cent., vi, no. 93, 1865.
Prohippelates pallidus, Malloch, Proc. U.S.N.M., xlvi, p. 260, 1913.

Only a single specimen of *Prohippelates pallidus* was taken in a fly trap situated at Papine, but this species is so different from all the others that no confusion should arise in its identification.

Description of Two New Species.

During the course of the island survey two new species of *Hippelates* flies were found. One was identified from at least thirty-two localities and the other from but three. Descriptions of these two new species are given below.

Hippelates turneri, n. sp.

Allied to *Hippelates nobilis*, Loew, and *Hippelates proboscideus*, Williston. Size about 2 mm.

♀. The vertical triangle is wholly pollinose, with the exception of the three ocelli; occasionally narrow semilunar bare areas are seen just lateral to the two posterior ocelli, but this is not a constant finding; the dusting on the vertical triangle is silvery or golden as in *H. nobilis*, but the fusiform bare area anterior to the median ocellus seen in *H. nobilis* is not present in *H. turneri*; the sides of the vertical triangle are straight; the essential differences in the vertical triangles of *H. nobilis*, *H. proboscideus*, and *H. turneri* are indicated in fig. 5. The frontal area between the eyes is yellow anteriorly and brownish towards the back; in some specimens the brownish coloration is so marked that it is difficult to distinguish the margins of the vertical triangle at all; sometimes also the posterior portion of the front, lateral to the vertical triangle, is pollinose. Cheeks are broad and yellow in front but brown behind. The third antennal joint is brown above and yellow below. The proboscis is yellow at the base but brown at the junction of the second and third segments. Palpi yellow.

The mesonotum is dark in colour and covered throughout with silvery or golden dusting. Three distinct double rows of hairs extend longitudinally, and between them are numerous other hairs arranged in irregular fashion. The scutellum also is dark and pollinose, except for its posterior margin which is reddish yellow. The apical scutellar hairs are large and well separated. The pleurae are black and pollinose except anteriorly, where the prothoracic lobes and often the adjacent area of the pleura are yellow instead of black.

The legs too are yellow; sometimes the posterior femora have a brownish band, but this is not a constant feature. There is a large spur or hook on the posterior tibia, which is longer than the tibial width and inserted terminally.

The abdomen is brownish, the first two segments usually being pale. The other abdominal segments each have two apical pale areas, which give to the basal brownish portion of each segment a scalloped or trilobed appearance. Halteres are pale yellow. The wings are hyaline and have the usual venation common to *Hippelates* flies.

Specimens of this species were taken chiefly in the white limestone areas of St. Ann and Manchester. The type locality, however, was Good Hope in the parish of Trelawny. A list of the 32 localities in which this species had been found follows.

Parish.		*Localities.*
Clarendon	...	Croft's Hill.
Hanover	...	Miles Town.
Manchester	...	Devon, Mile Gully, Newport, Williamsfield.
St. Andrew	...	Mount Pleasant, Papine.
St. Ann	...	Alderton, Bensonton, Britton Ville, Chalky Hill, Claremont, Colegate, Davis Town, Epworth, Fargus, Gloucester Hall, Mount Olivet, Orange Hill, Parry Town, Pedro, Philadelphia, River Head, St. Faith, Walker's Wood.
St. Catherine	...	Charlemont.
St. James	...	Roehampton.
St. Mary	...	Goshen.
Trelawny	...	Clark's Town, Good Hope, Troy.

Types will be deposited in the British Museum (Natural History), and paratypes in the United States National Museum, American Museum of Natural History (New York), at the London School of Tropical Medicine, and in the entomological collection of the Department of Agriculture of Jamaica.

This species has been named in honour of Dr. Thomas B. Turner, at whose suggestion the study of *Hippelates* flies, as potential vectors of yaws in Jamaica, was first begun.

Hippelates saundersi, n. sp.

Allied to *Hippelates dorsalis*, Loew, but smaller. Size about 1 mm.

♀. The vertical triangle has a brown centre round the three ocelli and yellow margins ; the sides are slightly concave. The frontal area between the eyes is brownish yellow. Cheeks very broad and yellow throughout. Proboscis yellow at base and brownish from the middle of the second segment to the distal end. Palpi yellow. The third joint of the antennae is brownish above.

In *H. dorsalis* the basal coloration of the mesonotum is uniformly dark grey. In *H. saundersi* the basal dark coloration is arranged in three stripes, that is, a broad central stripe extending on to the scutellum and two narrower lateral dark stripes as indicated in fig. 6. In *H. dorsalis* there are three distinct double longitudinal rows of hairs on the mesonotum. In *H. saundersi*, on the other hand, the mesonotal hairs have an irregular arrangement. Both species have a profuse golden dusting all over the mesonotum and scutellum. The basal coloration of the scutellum is dark anteriorly and yellow round its posterior margin. The apical scutellar bristles are widely separated. The pleurae in general are yellow, with the exception of two brown semilunar areas below. Prothoracic lobes yellow. The golden dusting extends from the mesonotum over the pleurae and prothoracic lobes.

The legs are brownish yellow with the last two tarsi darker than the rest. The tibial spur on the posterior legs is smaller than that in *H. dorsalis*, being not much larger than the width of the hind tibia. The tibial spur is inserted terminally.

The abdominal segments have apical pale areas, so that their basal brown zones have a trilobed appearance not unlike that seen in *H. turneri*. Halteres are pale yellow and the wings have the usual hyaline appearance.

Only three specimens of this species were obtained, the type locality being Alva in the parish of St. Ann. *H. saundersi* was also found at Devon and Porus in the parish of Manchester. The type specimen and one paratype will be deposited in the British Museum (Natural History). The other paratype is to be given to the American Museum of Natural History, New York. This fly is named in honour of Dr. George M. Saunders of the Jamaica Yaws Commission.

The Immature Stages of Hippelates pallipes, Loew.

The eggs, larvae, and pupae of *H. pallipes* have not been described previously. Herms & Burgess (1930) described those of *H. pusio*, and Patton (1921) those of a similar Indian eye-fly called *Siphunculina funicola*. Hall (1932) found that a higher percentage of the larvae of *H. pusio* pupated when they were fed on human excrement than when fed on any of the other breeding media which he tried, though the larval stage was shortest on a diet of dog manure. Marlatt (1933) reported that in California *H. pusio* bred only in light, loose, and freshly worked moist soils.

In Jamaica we have not as yet found out where *H. pallipes* breeds in nature. But plenty of eggs have been obtained by confining females, which had fed on blood or serum, in petri dishes with a little granulated sugar and water. Also a few adults have been reared from such eggs which were placed on wet sand, the larvae being fed on a mixture of decaying dog manure and rotting cardboard. Photomicrographs were taken of the ova, larvae and pupae of *H. pallipes*. The eggs are enlarged about 100 times, the larvae 125 times, and the pupae approximately 50 times.

The outstanding characteristics of the eggs are their white colour and shape, with irregular longitudinal striations and operculum at one end. The photomicrograph (Plate VII, fig. *a*) shows their appearance better than it could be described. The larva (Plate VII, fig. *b*) which was photographed was only a day or two old and hence shrank considerably during the fixation and staining processes. However, the twelve segments show up quite clearly, with the ventral protuberances located at the segmental lines. The buccopharyngeal apparatus was so poorly chitinized that it can hardly be seen in the photograph, and the posterior spiracles are unfortunately not in sharp focus.

The pupae (Plate VII, fig. *c*) were dark brown and flattened dorso-ventrally at the anterior end. Segmentation was indistinct, but striation quite apparent. There were two anterior and two posterior spiracles. The posterior spiracles are in better focus than the anterior ones. Small granules of sand and dirt were adherent to the surface of the puparium, and thus gave an irregular outline in places to the specimens in the photomicrograph.

Summary.

1. Fifteen species of Chloropidae were taken in a survey of Jamaica.

2. *H. pallipes*, Loew, was found in greater numbers and in more localities than any other species.

3. *H. peruanus*, Becker, was readily attracted to traps baited with decaying dead animal matter whereas *H. pallipes* came but rarely to such traps.

4. *H. pallipes* was most prevalent at elevations ranging from 101 to 1,500 feet above sea-level. *H. currani* was frequent somewhat lower down, and *H. pusio* and *H. illicis* were most common quite close to the sea.

5. A key with explanatory diagrams has been prepared for identifying the adult Chloropid flies of Jamaica.

6. Also the distribution records of all species captured during the island survey have been tabulated.

7. Two new species of *Hippelates* flies have been described.

8. Three photomicrographs of the immature stages of *H. pallipes* which were taken are briefly discussed.

Acknowledgments.

It is a pleasure to acknowledge the great assistance received in the preparation of this paper from Dr. C. H. Curran of the American Museum of Natural History, New York. Dr. Curran verified the identifications, and made suggestions as to the adult characters which would be of greatest value for taxonomic purposes. He also compared the following Jamaican flies with the types or paratypes, which are deposited at the American Museum of Natural History :—*H. currani*, Aldrich, *H. illicis*, Curran, *O. mars*, Curran, *O. tripunctata*, Curran, and *H. proboscideus*, Williston.

In addition Dr. Curran compared specimens of *H. nobilis*, Loew, and *H. flaviceps*, Loew, with the types of these flies which are located in the Museum of Comparative Zoology, Cambridge, Massachusetts. To Professor Nathan Banks of Cambridge, Mass., we are indebted for comparing Jamaican specimens of *H. pallipes*, *H. pusio*, and *H. dorsalis* with Loew's types which also are deposited in the collection at the Museum of Comparative Zoology.

Professor Szilady of the Hungarian National Museum, through the kind intercession of Dr. W. S. Patton of Liverpool, compared Jamaican specimens of *H. peruanus* with Becker's types; and reported that they were identical. And Dr. Oswald Duda compared *H. tibialis* taken in this island with flies identified as that species by him in his collection.

Finally the writer is very grateful to Mr. Denis M. Gick of Kingston for the photomicrographs of the immature stages of *H. pallipes*.

References.

Aldrich, J. M. (1905). Catalogue of North American Diptera.

——. (1931). Notes on *Hippelates* (*Diptera* : *Chloropidae*), with a new Brazilian species.—Proc. Ent. Soc. Wash., **33,** pp. 69–72.

Cottam, R. (1923). A description of a new species of Chloropid fly from Khartoum, and observations on certain of its habits.—Lanc. & Chesh. Nat., 1922–1923, pp. 101–104.

Curran, C. H. (1926). New Diptera from the West Indies.—Amer. Mus. Novit. no. **220,** pp. 4–5.

——. (1928). Insects of Porto Rico and the Virgin Islands. Diptera or two-winged flies.—Sci. Surv. P. R. & Virgin Is. **11,** pp. 44–50, 56.

——. (1931). First supplement to the "Diptera of Porto Rico and the Virgin Islands."—Amer. Mus. Novit. no. **456,** pp. 11–12.

Duda, O. (1931). Die neotropischen Chloropiden (Dipt.).—Folia Zool. Hydrobiol. **2,** pp. 46–128.

Gowdey, C. C. (1926). Catalogus Insectorum Jamaicensis.—Dep. Agric. Jamaica, Ent. Bull. no. **4,** p. 88.

Hall, D. G. (1932). Some studies on the breeding media, development and stages of the eye gnat *Hippelates pusio* Loew (Diptera : Chloropidae).—Amer. J. Hyg. **16,** pp. 854–864.

Herms, W. B. & Burgess, R. W. (1930). A description of the immature stages of *Hippelates pusio* Loew and a brief account of its life history.—J. Econ. Ent. **23,** pp. 600–603.

KUMM, H. W. (1934). Annual Report—Entomological studies made for the Jamaica Yaws Commission during 1934.—Jamaica Govt. Ptg. Off. pp. 19–30.

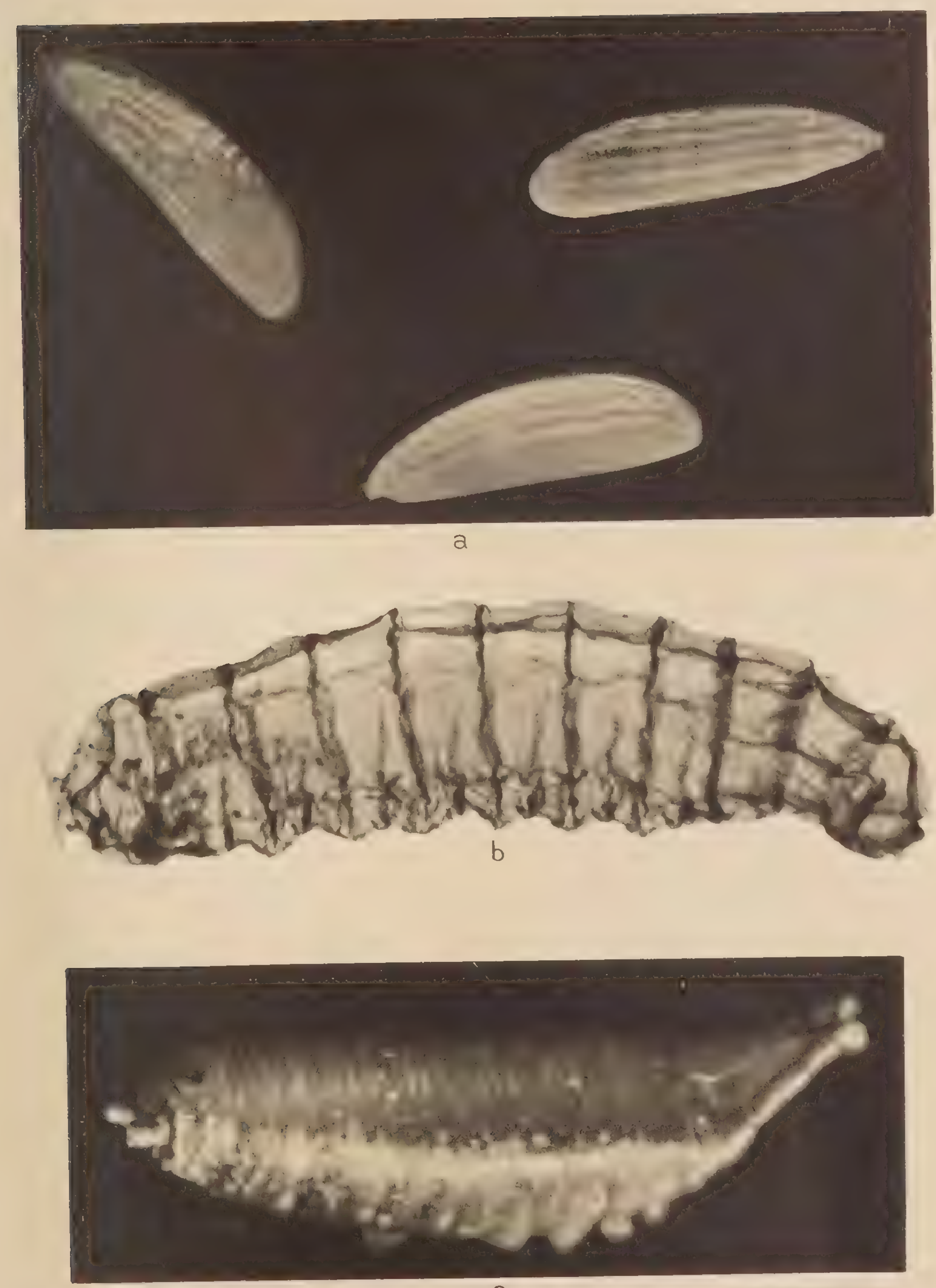
LOEW, H. J. (1861–72). Diptera americae septentrionalis indigena. Centuriae I-X.—Berliner Ent. Z. 1861–72.). In Centuriae the flies are numbered from 1 to 100, and these numbers, not pages, are given in all references. The page numbers in the Centuriae do not always agree with those in the Berliner Entomologische Zeitschrift.

MARLATT, C. L. (1933). Report of the chief of the Bureau of Entomology, 1933.—U.S. Dep. Agric. p. 39.

PARMAN, D. C. (1932). A box-type trap to aid in the control of eye gnats and blow flies.—Arc. U.S. Dep. Agric. no. **247.**

——. (1932). Construction of the box-type trap for eye gnats and blow flies.—Circ. U.S. Dep. Agric. Bur. Ent., Number E.299, mimeogr.

PATTON, W. S. (1921). Studies on the flagellates of the genera *Herpetonomas*, *Crithidia* and *Rhynchoidomonas* no. 3 ; The Morphology and life history of *Rhynchoidomonas siphunculinae* sp. nov. parasitic in the Malpighian tubes of *Siphunculina funicola* de Meijere.—Ind. J. Med. Res. **8,** pp. 603–612.



Hippelates pallipes, *a*, eggs (x 100); *b*, larva (x 125); *c*, pupa (x 50).

TWO NEW EGG-PARASITES OF *BATOCERA* (COL., LAMIID.) IN MALAYA.

By Ch. Ferrière, D.Sc.,
Imperial Institute of Entomology.

The Imperial Institute of Entomology has received from Mr. N. C. E. Miller, from Malaya, some interesting Chalcids, which have been bred from the eggs of *Batocera rubus*, L. Parasites of Cerambycidae are generally little known everywhere and only very few egg-parasites of beetles have yet been described. Mr. Miller's breedings are therefore of special interest and importance. We understand that he has made some biological observations, which he intends to publish; therefore, although very few specimens of these parasites have been received so far, we venture to describe them here with the material at hand. One species belongs to the Cleonymidae and to a very striking new genus, which can be confused with no other known genera; the other is the first species of *Ooencyrtus* known to attack eggs of Coleoptera.

Family Cleonymidae.

Louricia, gen. nov.

Head with the vertex very narrow, the eyes close to each other, the frons reduced to a narrow line between the eyes. Face prominent below the eyes, the cheeks very large, as long as the diameter of an eye. Antennal furrow well marked, rounded. Antennae with 10 joints: scape, pedicel, 2 annelli, 5 funicle joints and a solid club. Thorax elongate, with the pronotum conical and large, the parapsidal furrows complete, the axillae quadrate, their upper angles projecting in front, the scutellum rounded and cushion-like, the propodeon reduced almost to nothing in the middle, broad at the sides. Wings with rather long marginal and postmarginal veins, the stigmal vein very short, sessile. Legs narrow and long, the tarsi longer than the tibiae. Abdomen elongate, with the ovipositor strongly protruding.

This remarkable genus differs from all other genera of the Cleonymidae and is specially characterized by the form of the head, with the eyes close together on the upper anterior part of the head, by the antennae with only 10 joints, by the axillae projecting in front as in the Microcentri, by the very short stigmal vein (as in the Torymidae) and by the long tarsi.

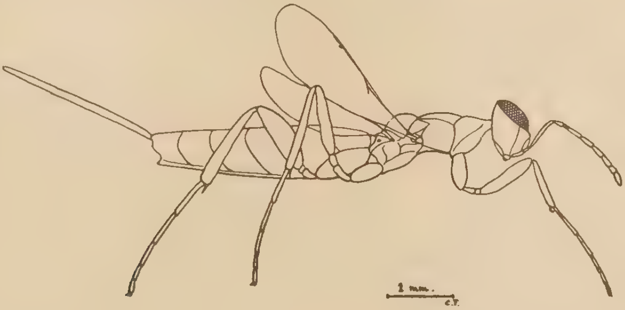


Fig. 1. *Louricia ovivora*, sp. n. ♀.

L. ovivora, sp. nov.

♀. Body black with greenish reflections, especially on the pronotum, the sides of the thorax and the base of the abdomen; face and cheeks with violaceous and bluish reflections; scutellum and abdomen aeneous; postscutellum white. Antennae and legs black, the tips of femora and tibiae yellow, the tarsi brown, with the first three joints of the middle pair and the first two joints of the hind pair white. Anterior wing slightly infuscate below the marginal vein and the end of the submarginal vein.

Head with the face and the antennal furrow shagreened, dull, the cheeks more shining and finely striate. Antennal furrow margined. Clypeus placed almost at a right angle to the face. Antennae inserted on the sides of the furrow; scape narrow, somewhat curved; pedicel narrow, almost as long as the 2/5 of the scape; the two annelli about twice as broad as long; 1st funicle joint 1·5 times as long as the pedicel, a little more than 4 times as long as broad, the following joints gradually shorter and a little broader, the 3rd as long as the pedicel, the 5th still 1·5 times as long as broad; club obliquely truncate, somewhat shorter than the two preceding joints together.

Pronotum finely striate, shining; propleurae strongly concave in the middle, the lower margins a little elevated above the front coxae. Mesonotum shagreened, dull, with the sides diverging posteriorly; parapsidal furrows deep and almost parallel. Scutellum longitudinally striate on the basal half, shagreened and almost shining on the second half. Axillae flat, finely striate. Mesopleurae narrow, partly hidden below the thorax. Propodeon almost smooth and shining on the sides, with small white ciliae. Front legs with the coxae elongate, the femora short, slightly curved, the tibiae shorter than the femora, the tarsi thin and almost twice as long as the tibiae; middle tibiae with the coxae short oval, the 1st trochanter twice as long as the 2nd, the femora slightly twisted, the tibiae a little longer than the femora, the tarsi longer than the tibiae; hind legs with strong and long coxae, the trochanters short, the femora a little thickened, the tarsi as long as the tibiae. Wings relatively narrow and short, not reaching to the end of the abdomen; marginal vein as long as 3/5 of the submarginal vein and twice as long as the post-marginal vein; stigmal vein very short, the end almost parallel to the postmarginal; the curve of the submarginal vein is thickened and bears below a short chitinous extension towards the base of the wing, terminating in a row of a few ciliae; discal ciliation short and close, from the end of the submarginal vein; marginal ciliae very short.

Abdomen narrow, the sides subparallel, about 1·5 times as long as thorax and head together. Ovipositor as long as 3/4 of the abdomen.

Length, 6 mm., ovipositor 2·5 mm.

Malaya: Rawang, 1 ♀, 7.iv.1934 (*N. C. E. Miller*).

Type in the British Museum; the antenna, wings and legs of the right side mounted on a slide.

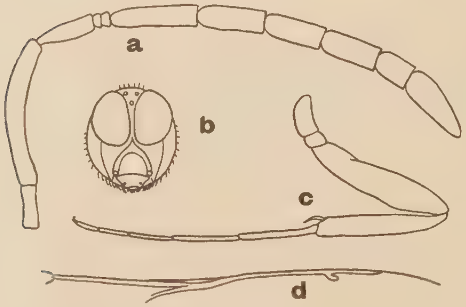


Fig. 2. *Louricia ovivora*, sp. n. ♀: *a*, antenna; *b*, head, frontal view; *c*, front leg; *d*, wing nervature.

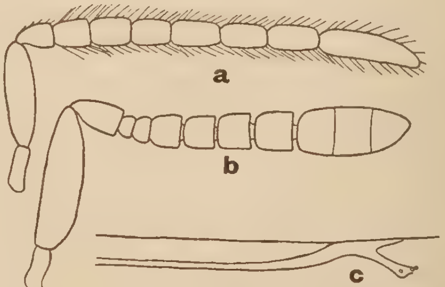


Fig. 3. *Ooencyrtus batocerae*, sp. n.: *a*, antenna of male; *b*, antenna of female; *c*, wing nervature.

Family ENCYRTIDAE.

Ooencyrtus batocerae, sp. nov.

♀♂. Body black, with dark metallic reflections. Antennae with scape and pedicel black, the tips yellowish, funicle light brown, club white. Legs yellow, the front and hind femora and tibiae more or less blackish. Wings hyaline.

♀. Head transverse, seen from in front rounded, the eyes converging slightly towards the vertex, the cheeks very short. Antennae inserted near the clypeus ; scape somewhat broadened, scarcely reaching the front ocellus, about four times as long as broad ; pedicel as long as 1/3 of the scape ; the first two joints of the funicle short and transverse, clearly smaller than the following joints ; joints 3 to 6 a little broader than the pedicel, but all shorter, subquadrate or slightly broader than long ; club with 3 joints, as long as the three preceding joints together.

Thorax as broad as long, finely shagreened, shining. Mesonotum more than twice as broad as long ; axillae narrow, meeting in the middle ; scutellum rounded, almost smooth ; propodeon only visible on the sides, where it is rounded. Wings reaching beyond the end of the abdomen ; marginal vein a little longer than broad ; stigmal vein narrow, slightly longer than the marginal ; postmarginal vein shorter and narrower than the marginal.

Abdomen oval, as long as or a little longer than head and thorax together. Ovipositor slightly protruding.

♂. Similar, differing only by its shorter abdomen, which is not longer than the thorax and more or less triangular, and by the form of the antennae, which are longer and more ciliate ; scape shorter, pedicel scarcely longer than broad, funicle joints all longer than broad, the last three a little longer than the first three, club solid, as long as the two preceding joints together.

Length : ♀ 1·1–1·2 mm. ; ♂ 0·9 mm.

MALAYA : Bukit Cheraka Forest Reserve, 2 ♀, 1 ♂, 10.v.1934 (*N. C. E. Miller*).

Type and cotypes in the British Museum, the type ♀ mounted on a card, the cotypes ♀ and ♂ on slides.

In our key to the Asiatic species of *Ooencyrtus*, Ashm. (Bull. Ent. Res., **22,** 1931, p. 282) this species would run near *O. corbetti*, Ferr., from the Malay Peninsula. It differs specially by its shorter antennae, where the first two funicle joints are transverse, distinctly shorter together than the pedicel, and the other joints subquadrate, by the white antennal club and by the almost smooth scutellum.

PESTS ATTACKING CITRUS IN JAMAICA.

By W. H. Edwards,
Government Entomologist.

Oranges, and to a lesser extent grapefruit, have been exported from Jamaica for many years but to an extent considerably under the potentialities of production of the country. In order that the Colony may derive full benefit from natural conditions definitely propitious to the growth of these crops, as well as from the possibilities afforded by an exceptionally advantageous geographical position with regard to world markets and trade routes, the Department of Agriculture is at present organising and developing production of citrus fruits for export on a much larger scale.

Circumstances have caused planters in Jamaica to have less opportunity to become entomologically minded than the agriculturists of other countries, and until recently little was ever done to combat pests attacking citrus. For the economic success and stable development of an industry such as citrus, pest control is, however, of outstanding importance, and entomological problems connected with this industry are receiving considerable attention by the Department of Agriculture.

The following are the pests which have been recorded as attacking citrus in Jamaica :—

Amongst the scale-insects, *Coccus viridis*, Green, *Lepidosaphes beckii*, Newm., and *Chrysomphalus aonidum*, L., are on the whole the most injurious species ; but the following have also been recorded :—*Orthezia* //*signis*, Dougl., *Pseudococcus citri*, Risso, //in *Pulvinaria psidii*, Mask., *Ceroplastes ceriferus*, And., *Coccus hesperidum*, L., *Saissetia hemisphaerica*, Targ., *Saissetia oleae*, Bern., *Chionaspis citri*, Comst., *Selenaspidus articulatus*, Morg., *Chrysomphalus aurantii*, Mask., *Parlatoria pergandii*, Comst., and *Parlatoria ziziphi*, Luc. The larvae of two weevils, *Prepodes vittatus*, L., and *Pachnaeus litus*, Germar, attack the roots and, when left uncontrolled, sometimes cause considerable damage, especially to young plantations. The Citrus Black Fly (*Aleurocanthus woglumi*, Ashby), which infests the leaves and causes the growth of sooty moulds on the rind of the fruit, which thus becomes very difficult to clean for export, is now under complete control by the recently introduced Eulophid wasp (*Eretmocerus serius*). Amongst the ants, *Solenopsis geminata*, F., causes injury by chewing the bark and tender tissues of young shoots, and also by fostering and disseminating *Coccus viridis* ; and this scale-insect is also spread by *Crematogaster brevispinosa*, Lund. The Pentatomid bug, *Nezara viridula*, L., has been recently observed in large numbers in groves where leguminous plants had been grown, causing young shoots and buds to wilt rapidly. Leaf-eating caterpillars, such as *Papilio cresophontes*, Cram., and *P. pelaeus*, F., and the bag-worm, *Oiketicus abbotti*, Grote, rarely occur in destructive numbers. In young groves outbreaks of Aphids frequently occur, the insects causing the dwarfing of young shoots ; and thrips and mites infest fruit produced in the drier regions.

Although a large number of pests have thus been recorded, no single species can be said to be of outstanding importance as regards the citrus industry as a whole. This state of affairs can be accounted for by the following facts :—

(1) In the mountainous parts of the country, where citrus usually grows, ecological conditions are extremely varied. Outbreaks of individual species, when such occur, thus remain localised in usually restricted areas.

(2) In several districts climatic conditions are definitely inhibitive to the excessive multiplication of scale-insects, the plants remaining free although control measures are actually never applied.

(3) Apart from a few exceptions where old regularly planted groves exist (these are usually situated in the more favoured areas), citrus is not grown in extensive groves in Jamaica. The greater part of the crops obtained up to the present is gathered from trees growing in a semi-wild condition amongst rank vegetation or in pasture lands. Being thinly scattered over extensive areas, conditions have remained naturally unfavourable to the spread and excessive multiplication of insect pests.

Whilst some of the conditions mentioned above are important assets on which growers can reckon when they contemplate increasing production by regular plantings, it must be borne in mind that the extension of plantations will in itself completely alter the conditions mentioned in (3). The writer believes that with regard to insect pests, citrus growers have up to the present benefited from a coincidence of favourable circumstances which have allowed them to give little attention to insect control, but that they are rapidly reaching a stage where those problems will become of outstanding importance for the success of their undertakings. With planters giving a reasonable amount of attention to pest control, there should be no difficulty in keeping existing pests in check, and at small expenditure ; but the writer believes that with the situation evolving in the direction mentioned above, and with a population still accustomed to a type of cultivation which the writer can only describe as contemplative, there are reasons for apprehending that the rate at which extension in planting takes place may exceed the necessarily slow rate of educating a large number of small growers who are turning their attention to citrus production as a casual source of revenue.

The attention of the Departmental officers in charge of citrus extension has been repeatedly called to the following essentials :—

(*a*) Citrus cultivation should on no account be encouraged where soil and other environmental conditions are not propitious to healthy growth, as economic control of scale-insects will only be achieved if the growth is normally vigorous.

(*b*) That plantations should be made according to a plan and on lands which might be made accessible to spraying instruments mounted on wheels.

(*c*) That prospective growers should be made to realise very clearly that even in their privileged situation, lasting success can only be achieved if they improve their methods of agriculture, including pest control, to a standard approaching at least that practised in other countries.

(*d*) That the application of insecticides to control scale-insects on citrus is bound to remain unremunerative when the trees grow in semi-wild conditions, scattered over extensive areas of pasture-lands or amongst thick growth of rank vegetation ; a state of affairs which with few exceptions is at present unfortunately of general occurrence in the Island.

(*e*) That the cost of treatment of a tree with an insecticide remains practically constant whether the tree bears a good or a bad crop. The amount spent on pest control is therefore relatively small where high yields of fruit of good quality are obtained, but becomes onerous where only a few fruits fetching low prices are obtained.

Except in the case of those who possess sufficiently extensive groves to warrant the purchase of adequate equipment and the training of labour, it is feared that control of scale-insects by means of insecticides will be a very difficult proposition for the majority of small growers, who will not be in a position to purchase relatively expensive instruments or apply insecticides judiciously. As there is little prospect of seeing, at least during the first stages of the development of citrus cultivation, peasant farmers purchasing adequate instruments for spraying the small number of trees which they individually possess, efforts are being made to induce firms engaged in the importation and sale of insecticides to build up organizations to undertake the application of the products with their own equipment and at a fixed price per tree.

This would be a rapid way for those firms to extend their sale of insecticides, and the small planter will become gradually familiarised with the application of artificial methods of control. There are still many difficulties which under present conditions undoubtedly render the economic aspect of such a venture hazardous for the undertaker, but it is hoped that these will be overcome. A co-operative organization which would own the necessary instruments and employ trained labour, working under the aegis of the Jamaica Agricultural Society, would be an alternative, if private enterprise does not take the initiative in the matter, as has been done in other countries.

THE PART PLAYED BY MICROCLIMATES IN ENABLING *GLOSSINA SUBMORSITANS* AND *G. TACHINOIDES* TO WITHSTAND THE HIGH TEMPERATURES OF A WEST AFRICAN DRY SEASON.

By T. A. M. Nash, D.Sc. (Lond.),

Entomologist, Tsetse Investigation, Northern Nigeria.

(Plates VIII & IX.)

Introduction.

Recently a description was published upon experiments on the effect of high maximum temperatures of *G. submorsitans*, Newst., and *G. tachinoides*, Westw. (Nash, 1935) ; as the present paper carries that investigation still further a summary of those results must be given :—

In Northern Nigeria the climate is so severe in the late dry season that tsetse are forced to evacuate the woodland savannah and to concentrate within the denser vegetation of stream-beds, or in the islands of forest that are found near the large rivers. It was believed that temperature played a large part in causing concentration and so the effect upon tsetse of the normal maximum temperatures at this season was observed.

Every morning young flies were fed and then placed in a wall-less grass hut situated under an evergreen tree ; the maximum temperature, its duration, and other factors were recorded for the day, and the number of deaths entered up on the following morning. A critical temperature zone for tsetse was demarcated :—Should the maximum shade temperature on any day enter this zone, then an unusually high mortality will occur, culminating in 100 per cent. mortality if the upper limit be reached. Using tsetse 0 to 1 day old, the critical zone for *G. tachinoides* is 103° to 105·5°F., and for *G. submorsitans* it is 103·5° to 106°F. ; with flies 11 to 12 days old, the critical zone is slightly lower, viz., *G. tachinoides* 102° to 105·5°F., and *G. submorsitans* 102·5° to 106°F.

The temperature within the grass house was very similar to that recorded in a Stevenson screen in the open bush which is evacuated by fly at this season, presumably because the shade temperature frequently rises above the upper limit of the critical zone. Even in the dense forest into which the tsetse population concentrates in the hot weather, a maximum of 104°F. was recorded in a Stevenson screen ; this led to a preliminary investigation of temperature conditions in microclimates in the forest, which showed that there were cooler sites than in the screen. The object of this paper is to describe a more detailed investigation into the maximum temperatures occurring in microclimates which might be frequented by tsetse on very hot days. Before dealing with this investigation a small experiment, designed to confirm the position of the critical zone, will first be described.

Experiment to confirm the Lower Limit of the Critical Zone.

Since the basic data for the investigation has been obtained in a grass hut, with a climate similar to that of shade conditions in the open, evacuated fly bush, it was desirable to confirm the lower limit of the critical zone within the forest where tsetse were numerous.

The flies were kept in cages suspended from the lower branches of a tree, and eight feet above the ground level (no. vii site, Plate IX, fig. 1). There was a canopy of high shade, as well as an accumulation of debris at the base of the branches, which protected the cages from the sun's rays.

This experiment aimed at obtaining natural conditions and, since it was only to be in the nature of a check, it was decided to sacrifice the value of standardised age in return for the advantages of using flies of different ages which would be more representative of a tsetse community.

The experiment started with 39 *G. tachinoides* and 41 *G. submorsitans* 1 to 7 days old ; freshly emerged fly were added daily so as to keep up the population as in nature, and, since the investigation lasted for six weeks, it would have been *possible* for some individuals to be seven weeks old by the end. It is very much doubted whether any individuals survived a month, if as long, since from a longevity marking experiment with wild flies a month appeared to be the maximum age at this season. At 8 a.m. all deaths and the maximum temperature for the previous day were recorded ; the new and old flies were fed and then returned to their large, hanging, wire-gauze cages where they were left to face the rising temperature.

Since the results are bulky, and similar figures for the grass house experiment have already been published, detailed figures will not be given ; however, it was found that for fly up to three weeks old the lower limit for both species was 102°F.

TABLE I.

The continued adverse effect of two days' maximum temperature in the critical zone upon a community of G. tachinoides *and* G. submorsitans, *containing old individuals.*

Date	*G. tachinoides*		Maximum temp. for the day	*G. submorsitans*	
	No. of fly alive	Percentage dead next morning		No. of fly alive	Percentage dead next morning
			°F		
May 2nd ...	15	7	101·5	33	12
,, 3rd ...	22	50	103·0	31	39
,, 4th ...	17	41	103·0	21	48
,, 5th ...	14	50	100·0	14	36
,, 6th ...	13	31	101·8	16	31
,, 7th ...	9	44	100·8	11	18
,, 8th ...	18	22	100·8	19	11
,, 9th ...	24	8	101·5	19	11

(Previous findings :—Fly 11–12 days old, *G. tachinoides* 102°F., and *G. submorsitans* 102·5°F.) On no day was the upper limit for either species reached, but on a day when 104°F. was the maximum 61 per cent. of 46 *G. tachinoides* succumbed, and 34 per cent. of 47 *G. submorsitans* ; clearly such a site as the one employed would not enable the tsetse to escape the effect of high temperature, even though inside the forest.

Later, when the fly varied in age from one day to *possibly* seven weeks, it was no longer possible to delineate the lower limit, as many old and weakly insects would succumb after temperatures as low as 100°F., their resistance having been presumably weakened by the previous very hot days. This will be seen from Table I, where a temperature of 101·5°F. did little harm, but after two days at 103°F., a maximum on the following day of only 100°F. was followed by the deaths of many of the weakly survivors ; it was not until some days afterwards (8th and 9th May) that temperatures below the critical zone ceased to be followed by abnormally high death rates. Towards the end of the experiment a temperature of 100·5°F., following upon cool days, was sufficient to increase the mortality among *G. tachinoides*, but the lower limit remained at 102°F. for *G. submorsitans*.

Summary.—1. With flies not older than three weeks the lower limit of the critical zone is 102°F., for both species.

2. With flies not older than seven weeks the lower limit for *G. tachinoides* appears to drop to 100·5°F. ; the lower limit for *G. submorsitans* remains at 102°F.

3. With flies not older than seven weeks, the adverse effect upon the tsetse, of a day when the maximum temperature enters the critical zone, is continued for several days following, even though the maximum temperature on these days remains below the lower limit.

The Microclimates in the Forest.

In parts of Northern Nigeria, especially near the large sand rivers that only flow in the rains, one finds relics of closed forest in the form of riverine strips or forest islands surrounded by savannah woodland. A patch of this residual forest is rarely a homogeneous unit, as it is usually built up of clumps of true forest cemented into a whole by a windbreak of protective, peripheral thicket, which intrudes into the forest in tongues, whenever there is an absence of high shade. In the area selected the "true forest" was composed mainly of tall *Diospyros mespiliformis* (ebony trees), with crowns united by lianas to form dense high shade, which permits only dappled sunlight to reach the rich humus floor which is almost free from undergrowth ; in sharp distinction is the "intrusive thicket" of *Dichrostachys platycarpa*, growing like a huge impenetrable bramble up to 12 feet in height, choking the glades and accessible to uninterrupted sunlight at mid-day (Plate VIII).

Maximum temperatures were recorded throughout the hot season in the Stevenson screen and in eight microclimates ; brief notes upon the sites selected for the thermometers will now be given :—

(1) The thermometer was placed on the ground underneath the horizontal trunk of a huge liana, with heavy high shade from tall ebony trees. Sometimes leaves blew over the bulb, which was always inaccessible to the sun. Another part of the liana was also used (Plate IX, fig. 4).

(2) On the ground at the foot of a tree, enshrouded with dead creeper and *Dichrostachys platycarpa*, with heavy, high shade from creeper mats. Leaves never blew over the bulb, which was unlikely to be reached by even dappled sunlight (Plate IX, fig. 3).

(3) Fifteen inches above the ground, inside a large, hollow, horizontal trunk of a liana, full of humus. The bulb was inaccessible to the sun (Plate IX, fig. 4).

(4) On the ground under, and at the edge of, a dense intrusive thicket of *Dichrostachys platycarpa* ; a natural roof of dead leaves, supported on the stems of the bramble, lay six inches above the thermometer, which was inaccessible to the sun (Plate IX, fig. 5).

(5) Three inches above the ground, on the trunk of a tree which supports a creeper mat in its crown. An intrusive thicket glade starts thirteen feet away from the tree, so that direct sunlight penetrates the forest at this distance from its base. In the late afternoon dappled sunlight may fall on the bulb (Plate IX, fig. 1).

(6) Four feet above the ground in the Stevenson screen, which stands under a very dense, high canopy of creeper mat (Plate IX, fig. 2).

(7) Eight feet above the ground on the same tree-trunk as no. 5 and just under the roof of debris in the fork. Inaccessible to sunlight. The fly cages mentioned in the experiment described were suspended near this thermometer (Plate IX, fig. 1).

(8) Two feet seven inches above the ground and fixed to the bark of the same tree that was described under No. 2. At about 10 a.m. filtered sunlight used to fall on the bulb (Plate IX, fig. 3).

(9) Three feet four inches above the ground and suspended among the green leaves of a thick creeper. Heavy, high shade. Dappled sunlight falls on the creeper, but it is improbable that it ever reaches the bulb. The site is only twenty feet from the forest edge in a place where there is no peripheral thicket windbreak (Plate IX, fig. 6).

It is considered that these sites represent all the probable microclimates that tsetse might frequent during periods of dangerously high temperatures. Eight of the sites were in true forest, and only one (no. 4) was in intrusive thicket, where being on the fringe it had the advantage of some adjacent high shade.

For 52 days the maximum temperatures were recorded daily and in Table II the nine sites investigated are arranged in the ascending order of their respective mean maximum temperatures, reading from left to right.

If it is agreed that no. 3 is equivalent to a site on the ground, since the thermometer lay on humus inside the liana, it becomes evident that the ground sites lie together, giving mean maximum temperatures between 93° and 97°F., whereas the above-ground sites (3 inches to 8 feet) give means between 98° and 100·4°F. The mean of the mean maximum temperatures for the ground sites 1 to 4 is only 4·4°F., lower than the mean for the five above-ground sites—5 to 9; the cooling effect of the soil evaporation must be relatively small, presumably because the humus has already surrendered most of its moisture earlier on in the dry season, when the harmattan wind was blowing.

Turning now to the second horizontal column it will be seen that of the four ground sites only no. 4 produced an absolute maximum within the critical zone; it is significant that this was the only ground site in a glade of intrusive thicket. Probably it gives a very conservative estimate of the degree of heat experienced within this type of vegetation, because the site was only on the fringe of thicket, and so benefited by some high shade from the surrounding true forest, further there was a somewhat unusual roof of debris immediately above the instrument; if despite these advantages the ground temperature can attain to the upper fatal limit for *G. tachinoides*, it would appear that intrusive and peripheral thicket is unlikely to afford tsetse a sanctuary on very hot days. Since even in the forest the absolute maxima for the above-ground sites lie above the lower temperature limit in every case, it would appear probable that on the hottest days tsetse must rest on the ground within the forest proper; it is not easy to prove this by observation, as at mid-day tsetse are almost inactive, and the combination of their protective colouring with the poor light conditions prevailing in the forest makes their detection very difficult.

Professor Buxton has tentatively suggested to the writer that possibly under the influence of high temperature tsetse may be compelled to feed in order to cool themselves by evaporation, and that had the flies in the grass house experiment been given an opportunity to feed again at mid-day they might have been able to withstand a greater degree of heat than appeared from the results on the critical zone. Casual observation in the field tends to discount this possibility, as in the heat of the day tsetse tend to become inactive and do not attack the observer with unusual vigour; however, much more precise work will be carried out on this question of activity at mid-day, as well as further observations on their choice of resting sites in the heat of the day.

TABLE II.

Summary of Maximum Temperature Data from nine Microclimates in Riverine Forest, recorded over a Period of 52 *Days* (10*th April to* 31*st May*, 1935).

	1	2	3	4	5	6	7	8	9
	On ground under horizontal trunk of liana	On ground at foot of tree enshrouded with dead creepers	15in. above ground, lying on humus inside hollow, horizontal trunk	On ground on edge of intrusive thicket	3in above ground at foot of tree with high canopy	4ft. above ground inside Stevenson screen	8ft. above ground on trunk under tree's crown, *cf.* no. 5	2ft. 7in. above ground on trunk of tree enshrouded with dead creeper, *cf.* no. 2	3ft. 4in. above ground, in a creeper among growing leaves, near forest edge
Mean maximum over 52 days	92·9°F.	93·7°F.	95·5°F.	97·2°F.	98·2°F.	98·9°F.	99·1°F.	99·3°F.	100·4°F.
Absolute maximum	98·6°	99·0°	101·5°	105·°5	102·8°	106·0°	104·3°	104·0°	107·6°
Days when max. 102°F. or over (L.L. old *G. tach.*)	0	0	0	8	5	10	14	11	24
102·5°F. or over (L.L. old *G. submors.*)...	0	0	0	5	1	8	8	9	19
103·0°F. or over (L.L. young *G. tach.*) ...	0	0	0	3	0	4	7	9	17
103·5°F. or over (L.L. young *G. submors.*)	0	0	0	3	0	3	7	2	11
105·5°F. or over (U.L. for *G. tach.* 100 per cent. fatality)	0	0	0	1	0	1	0	0	3
106·0°F. or over (U.L. *G. submors.* 100 per cent. fatality)	0	0	0	0	0	1	0	0	2

The number of days, out of the 52, upon which the temperature entered the critical zone is shown for each site in the remaining horizontal columns of Table II. The letters L.L. and U.L. in the first vertical explanatory column refer to the Lower Limit and Upper Limit of the critical zone, so that " L.L. old *G. tach.*" means that 102°F. is the lower limit of the zone for 12 days old *G. tachinoides*, as found in the accurate grass-house experiment (Nash, 1935).

It will be seen that in six out of the nine sites the lower limit for 10 to 12 day old tsetse of both species was frequently reached ; in three sites the upper fatal limit for *G. tachinoides* was attained with temperatures of 105·5°F. or over, and in two sites the upper limit for *G. submorsitans* was reached with temperatures of 106°F. or over. The high temperatures recorded in site no. 9 are considered to be due to its situation ; it is only twenty feet from the forest edge in a place where the true forest extends to the margin without the usual intervening peripheral thicket windbreak ; these readings give an indication of what conditions might be like in the true forest were the peripheral and intrusive thickets removed.

Examination of the daily maximum temperatures shows that the effect of a shower of rain varies according to the position of the microclimate. Generalising, one can say that for ground sites a shower produces about twice as great an initial drop and that temperatures remain abnormally low for about twice as long, as for sites above the surface of the soil. For example, rain fell on 11th May and next day no. 4 site (on ground in thicket) gave a maximum that was 20°F. lower than the previous average, and it was 10 days before the temperature re-attained its pre-rain maximum ; at the same time no. 9 site (3 ft. 4 ins. above ground, among leaves of creeper) only dropped 9 F. on the day following rain, and it was only six days before its maximum temperature had returned to the pre-rain level.

In this part of Northern Nigeria the period from April to late June is one of transition between the late dry season and the advent of the heavy rains. It usually takes three months of occasional storms, some very heavy, before the rains start in earnest in July. The incidence of rain in this transition period is exceedingly varied ; for example, in April and May 1934, 5·4 and 3·5 inches, respectively, were recorded, whereas in April and May of this year (1935) there was only 0·07 and 0·5 inches, respectively. Clearly in 1934 one would not expect to obtain such high temperatures in the microclimates as in 1935 ; this was actually the case with some preliminary experiments that were carried out, as the forest never dried up after the precipitation of 2 inches of rain on 8th April. Since the hot season does not start until March, there was only one month of stress for the fly community in 1934 as compared with three months in 1935 ; further, the period of low fly density was abnormally protracted and accentuated in 1935.

General Summary.

1. It has been confirmed that the lower limit of the critical zone, for fly of medium age, is 102°F. for both species ; this limit is probably even lower for very old *G. tachinoides*.

2. The adverse effect upon the fly community of a day when the maximum temperature enters the critical zone is continued among the older individuals for several days following, even though the maximum temperature on these days remains below the lower limit.

3. From the mean maximum temperatures recorded over 52 days in 9 microclimates, it would appear that sites on the ground are cooler than those above the surface ; the difference is not very great, the mean for the four ground sites being only 4·4°F. lower than the mean for the five above-ground sites.

4. The evidence suggests that on very hot days only the ground within the true forest is safe for tsetse ; in all other sites—above the ground in the true forest or on

the ground in the intrusive and peripheral thickets—the temperature is liable to enter the critical zone, and may even reach the upper fatal limit.

5. The tsetse community is living very close to the critical zone in the late dry season. Even the coolest ground site yielded an absolute maximum that was only 3·5°F. below the lower limit.

6. Site no. 9 gives an indication of how severe the conditions might become in the true forest were the windbreaks of peripheral and intrusive thicket removed.

7. In ground sites a shower of rain produces about twice as great an initial drop in temperature, and temperature remains abnormally low for about twice as long, as it does for sites above the surface of the soil.

8. The duration of the period of dangerously high temperatures to which the fly community is subjected in the late dry season may be very varied ; it depends upon the incidence of rain in April and May.

Practical Application of the Results of the Experiments.

The most important conclusion to be derived from this work is that the tsetse live very close to the critical temperature zone in the late dry season, which supports the writer's tentative suggestion (Nash, 1935) that should the peripheral and intrusive thicket windbreaks *only* be removed it is quite possible that the insulation of riverine forest and forest islands would be destroyed, and that the hot winds from the open, burnt country would sweep through and so desiccate the forest floor, that the microclimates on the ground would not be appreciably cooler than those above the ground. Should the practical application of these results confirm this tentative suggestion, the economic value of this work will be great, since it will be possible to leave the valuable timber trees and only clear the useless thicket.

The writer's present plans are to continue research under natural conditions in this area for another year, and then, having obtained a basic understanding of the ecology of both species of tsetse in their habitat, to remove the thickets as described and observe the results on the fly community and on the maximum temperatures in the microclimates. In this way a really scientific knowledge of the exact effect of partial clearing on fly will be obtained, and if the method is put into practice in the field it will be far easier to estimate correctly under what circumstances partial clearing is likely to succeed.

Conclusions and Acknowledgments.

The results in this paper are considered to have considerably strengthened the chances of the success of partial clearing, by demonstrating that even though the microclimates on the soil surface are the probable secret of the tsetse's survival under natural conditions, yet even on the ground the temperature approaches dangerously near to the lower limit of the critical zone, especially in years when the rains are late.

The writer wishes to make acknowledgments to Dr. H. M. O. Lester, Director of the Tsetse Investigation, for having made it possible for this investigation to be carried out ; acknowledgments are also due to Mallam Ibraham and Mallam Dau whose assistance has been invaluable.

References.

Nash, T. A. M. (1935). The effect of high maximum temperatures upon the longevity of *Glossina submorsitans* and *Glossina tachinoides.*—Bull. Ent. Res. **26,** pp. 103–113.

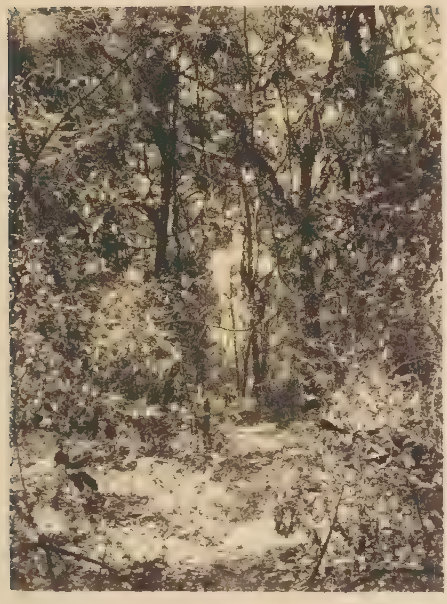


Fig. 1. The true forest.

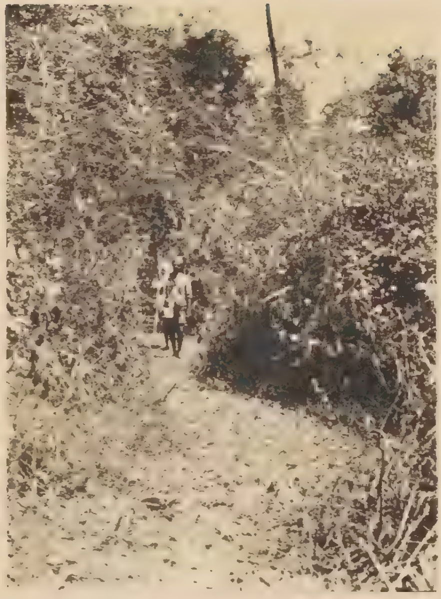


Fig. 2. Intrusive thicket.

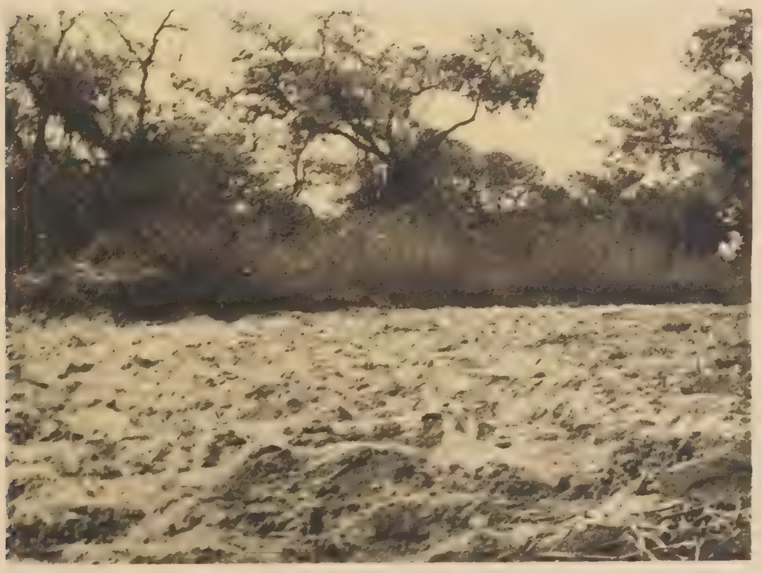


Fig. 3. Windbreak of peripheral thicket.

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THE TWO COMPONENTS OF RESIDUAL FOREST: TRUE FOREST AND PERIPHERAL OR INTRUSIVE THICKET

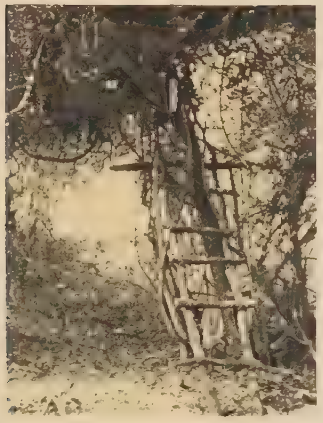

Fig. 1. Site VII. Eight feet up tree.
Site V. Near foot of tree.

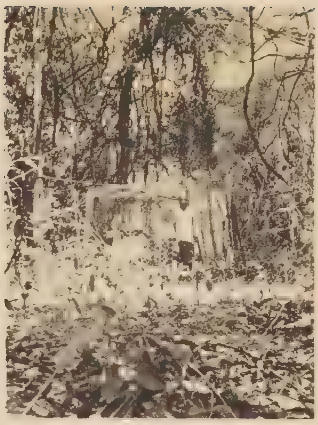

Fig. 2. Site VI. In Stevenson screen
in Meteorological Station.

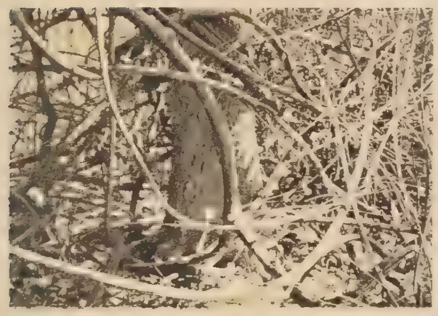

Fig. 3. Site VIII. (Upper arrow).
Site II. (Lower arrow).

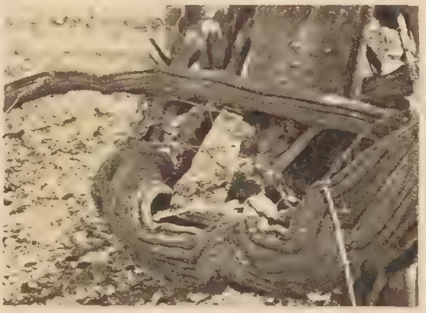

Fig. 4. Site III. Inside liane.

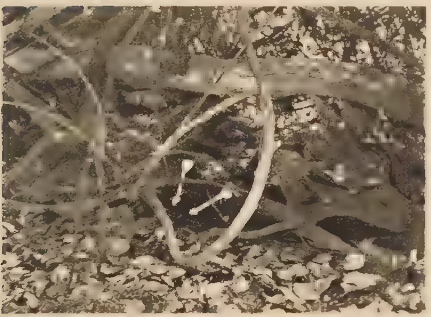

Fig. 5. Site IV. At edge of intrusive thicket.

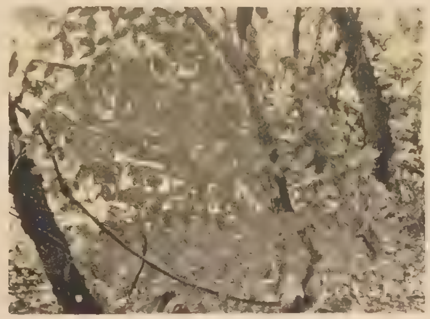

Fig. 6. Site IX. Amid leaves of creeper.

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ILLUSTRATING THE SITES IN WHICH MICROCLIMATES WERE INVESTIGATED.

COLLECTIONS RECEIVED.

The following collections were received by the Imperial Institute of Entomology between 1st January and 31st March, 1936 :—

Agricultural Research Service, Khartoum :—17 Diptera, 63 Coleoptera, 512 Parasitic Hymenoptera, 2 Lepidoptera, 11 species of Coccidae, 1 species of Aphidae, 1 species of Aleurodidae, 30 Cimicidae, 67 other Rhynchota, 500 Mites, 5 Spiders, and 8 Snail shells ; from the Sudan.

Mr. A. E. Aitkens :—3 Parasitic Hymenoptera ; from Aberdeen.

Dr. H. F. Barnes, Rothamsted Experiment Station :—1,708 Parasitic Hymenoptera ; from England.

Berlin Museum :—478 Parasitic Hymenoptera ; from Europe.

Dr. F. S. Bodenheimer :—801 Coleoptera and 5 larvae, 6 Hymenoptera, 2 Rhynchota, 155 Orthoptera, 2 Dermaptera, 10 Collembola, and 4 Mites ; from Palestine.

Dr. G. Bondar :—138 Coleoptera ; from Brazil.

Mr. P. Borg :—1 species of Coccidae : from Malta.

Mr. H. E. Box :—21 Coleoptera ; from St. Lucia and Guadeloupe.

Mr. H. Britten, Manchester Museum :—41 Parasitic Hymenoptera ; from England.

Mr. E. Burtt : - 22 Diptera, 3,653 Coleoptera, 112 Hymenoptera, 2 Lepidoptera, 43 Isoptera, 108 Rhynchota, 2 Orthoptera, and 5 Ticks ; from Tanganyika Territory.

Mr. F. G. Chen :—14 Diptera, 18 Coleoptera, 17 Lepidoptera, 6 Rhynchota, and 4 Orthoptera ; from China.

Chief Entomologist, Pretoria :—12 Diptera, 5 Lepidoptera, and 2 species of Aleurodidae ; from South Africa.

Mr. J. T. Chu :—4 Lepidoptera ; from China.

Mrs. A. Clay :—30 Coleoptera ; from Derbyshire.

Coconut Experiment Station, Celebes :—16 Parasitic Hymenoptera ; from the Dutch East Indies.

Father P. A. Conrads :—387 Coleoptera ; from Tanganyika Territory.

Mr. G. H. Corbett, Government Entomologist :—8 Diptera, 46 Coleoptera, 210 Parasitic Hymenoptera, 51 other Hymenoptera, 65 Lepidoptera, 19 Rhynchota, 1 Tick and 100 eggs, 2 Millipedes, and 10 Parasitic Worms ; from Malaya.

Coryndon Memorial Museum, Nairobi :—1,118 Coleoptera and 355 Rhynchota ; from East Africa.

Mr. A. Cuthbertson, Assistant Entomologist :—14 Coleoptera and 2 Rhynchota ; from Southern Rhodesia.

Mr. R. C. M. Darling :—5 Lepidoptera and 376 Orthoptera ; from the Sudan.

Director of Public Works, Lagos :—100 Isoptera ; from Nigeria.

Empire Cotton Growing Corporation :—4 Parasitic Hymenoptera and 50 Formicidae ; from South Africa.

Mr. J. Feytaud :—15 Parasitic Hymenoptera and 6 other Hymenoptera ; from France.

Mr. J. C. M. Gardner, Systematic Entomologist : –205 Parasitic Hymenoptera, and 40 cocoons, and 66 Lepidoptera ; from the United Provinces, India.

Mr. C. C. Ghosh :—130 Coleoptera ; from Burma.

Mr. G. Gilby :—15 Coleoptera ; from England.

Government Entomologist, Coimbatore :—76 Diptera and 18 pupa cases, 23 Coleoptera ; 46 Parasitic Hymenoptera, and 20 Lepidoptera ; from South India.

Government Entomologist, Kampala :—44 Diptera, 225 Coleoptera, 1,600 Parasitic Hymenoptera, 86 Rhynchota, and 3 Orthoptera ; from Uganda.

Government Entomologist, Lyallpur :—79 Coleoptera, 13 Parasitic Hymenoptera, 100 Apidae, 3 Lepidoptera and 8 early stages, 3 species of Coccidae, 5 species of Aphidae, and 1 species of Psyllidae ; from the Punjab.

Mr. K. Guichard :—9 Curculionidae ; from New South Wales.

Mr. E. Hargreaves, Government Entomologist :—5 Tabanidae, 119 other Diptera and 4 pupa cases, 190 Coleoptera, 54 Parasitic Hymenoptera, 15 other Hymenoptera, 92 Lepidoptera, 700 Isoptera, 4 Thysanoptera, 16 Rhynchota, 11 Orthoptera, 9 Planipennia, and 22 Trichoptera ; from Sierra Leone.

Mr. K. J. Hayward :—6 Coleoptera, 73 Parasitic Hymenoptera, 14 Lepidoptera, and 6 Chrysopidae ; from Argentina.

Mr. H. J. Hockings :—4 Lepidoptera, 3,000 Isoptera, and 1 species of Coccidae ; from Queensland.

Mr. W. E. H. Hodson :—2 Diptera and 2 pupa cases ; from England.

Mr. Y. Hukkinen :—200 Parasitic Hymenoptera ; from Finland.

Imperial Entomologist, Pusa :—91 Diptera, 249 Coleoptera, 30 Parasitic Hymenoptera, 48 other Hymenoptera, 7 Lepidoptera, 400 Isoptera, 83 Rhynchota, 7 Orthoptera, 3 Embiidae, 3 Ephemeridae, 3 Trichoptera, and 7 Mites ; from India.

Institute for Plant Diseases, Buitenzorg :—163 Coleoptera, 42 Lepidoptera, and 7 Rhynchota ; from the Dutch East Indies.

Dr. C. A. Isaakides :—14 Parasitic Hymenoptera ; from Greece.

Mr. L. N. Johri :—50 Siphonaptera, 10 Diptera, 128 Coleoptera and 3 early stages, 4 Parasitic Hymenoptera, 12 other Hymenoptera, 11 Lepidoptera and 29 early stages, 30 Isoptera, 3 species of Coccidae, 1 species of Aphidae, 23 other Rhynchota, 10 Psocidae, 9 Orthoptera, 3 Odonata, 20 Ephemerid skins, 10 Mallophaga, 10 Mites, and 12 Spiders ; from Burma.

Mr. C. B. R. King :—9 Diptera and 2 pupa cases, 28 Parasitic Hymenoptera and 20 cocoons ; from Ceylon.

Mr. R. A. Lever, Government Entomologist :—18 Culicidae, 75 Diptera, 220 Coleoptera, 150 Parasitic Hymenoptera, 20 Formicidae, 52 Lepidoptera, 50 Thysanoptera, 2 species of Coccidae, 100 other Rhynchota, and 2 tubes of Entomogenous fungi : from the Solomon Islands.

Dr. E. A. Lewis, Veterinary Entomologist :—14 Tabanidae, 9 Hippoboscidae, 28 *Glossina*, 21 *Auchmeromyia*, 2 *Cordylobia*, 88 other Diptera, 5 Coleoptera, 13 Rhynchota, and 2 Orthroptera ; from Kenya Colony.

Dr. A. Da Costa Lima :—15 Coleoptera ; from Brazil.

Mr. C. J. Louwerens :—68 Curculionidae ; from the Dutch East Indies.

Mr. A. Manjikul :—100 Parasitic Hymenoptera, 50 Formicidae, and 20 early stages ; from Siam.

Mr. C. Manolache :—100 Parasitic Hymenoptera ; from Rumania.

Prof. F. J. Meggitt :—8 Coleoptera and 8 early stages, and 20,000 Isoptera ; from Burma.

Mr. H. M. Morris, Government Entomologist :—80 Parasitic Hymenoptera, 8 Formicidae, and 24 Lepidoptera ; from Cyprus.

Mr. M. C. Mossop, Assistant Entomologist :—2 Coleoptera ; from Southern Rhodesia.

Mr. J. Muggeridge, Government Entomologist :—12 Parasitic Hymenoptera and 2 Lepidoptera ; from New Zealand.

Dr. J. G. Meyers :—75 Lepidoptera ; from British Guiana.

Mr. W. Nägeli :—40 Parasitic Hymenoptera ; from Switzerland.

Mr. F. B. Notley, Assistant Entomologist :—12 Coleoptera ; from Kenya Colony.

Paris Museum :—36 Curculionidae : from the New Hebrides.

Mr. E. F. Peck, Veterinary and Agricultural Officer :—150 Orthoptera ; from British Somaliland.

Rev. O. Piel :—144 Coleoptera ; from China.

Mr. J. Pirie :—7 Rhynchota ; from the Gambia.

Mr. M. Quilis :—11 Parasitic Hymenoptera ; from Spain.

Mr. P. Regnier :—50 Diptera and 4 pupa cases, 400 Parasitic Hymenoptera and 34 Orthoptera ; from Morocco.

Mr. A. H. Ritchie, Government Entomologist :—150 Curculionidae and 100 larvae ; from Tanganyika Territory.

Mr. K. Roos :—26 Parasitic Hymenoptera ; from Switzerland.

Selangor Museum :—7 Diptera and 281 Coleoptera ; from Malaya.

Mr. Nihat Shevket :—33 Diptera, 52 Coleoptera, 2 Parasitic Hymenoptera, 31 other Hymenoptera, 46 Lepidoptera, 1 species of Aphidae, and 10 Earthworms ; from Asiatic Turkey.

Mr. C. Smee, Government Entomologist :—44 Coleoptera and 23 Orthoptera ; from Nyasaland.

Mr. F. A. Squire, Government Entomologist :—24 Diptera, 52 Coleoptera, 66 Parasitic Hymenoptera, 5 other Hymenoptera, 15 Lepidoptera, 3 species of Coccidae, 93 other Rhynchota, 6 Orthoptera, and 2 Mantispidae ; from British Guiana.

Mr. C. B. Symes, Medical Entomologist :—4 *Tabanus*, 686 other Diptera, 17 Coleoptera, 7 Parasitic Hymenoptera, 25 other Hymenoptera, 38 Lepidoptera, 76 Rhynchota, 3 Orthoptera, 7 Ephemeridae, and 2 Spiders ; from Kenya Colony.

Dr. P. Tchorbadjiev :—34 Orthoptera ; from Bulgaria.

Mr. J. A. J. Thompson :—86 Coleoptera, 2 Hymenoptera, 176 Lepidoptera, 22 Rhynchota, and 7 Orthoptera ; from Tanganyika Territory.

Mr. P. Vayssière :—61 Parasitic Hymenoptera ; from the New Hebrides.

Mr. F. G. S. Whitfield :—50 *Simulium*, 45 other Diptera, 11 Coleoptera, 7 Lepidoptera, 3 Rhynchota, and 7 Orthoptera ; from the Sudan.

Mr. H. Wilkinson, Entomologist :—14 Coleoptera, 26 Parasitic Hymenoptera, 200 Thysanoptera, 1 species of Coccidae, and 24 other Rhynchota ; from Kenya Colony.

EXPERIMENTAL STUDY ON THE DEVELOPMENT OF THE OVARY IN *ANOPHELES ELUTUS*, EDW. (DIPT. CULIC.).

By G. G. Mer,

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Hibernation is still one of the obscure phenomena in the bionomics of *Anopheles*, for the nature of hibernation itself, as well as the associative changes of fat deposition and retarded ovarian development, have not as yet been made clear. Despite the extensive investigations on the subject, the factors responsible for hibernation remain unknown.

Since retardation of development of the ovaries is one of the striking phenomena associated with hibernation, we undertook an experimental study of ovary development under different conditions, in the hope that an understanding of the factors influencing or determining this development would shed light on the factors involved in hibernation.

Development of the Ovary without Food.

Newly emerged *Anopheles elutus* females examined shortly after their emergence present the pupal air-tubes intact, and the midgut contains a brownish-green amorphous mass.

At this stage of the life of the imago the ovary is, in most of the females, very small and the follicles contain eight undifferentiated cells. Only in some instances are the follicles in a later stage of development; in these the ovum is differentiated from the rest of the cells and, exceptionally, the cytoplasm of the ovum may contain a few yolk granules. For example, *A. elutus* females which emerged in May, June and July, were dissected ten minutes to one hour after emergence and gave the following results (Dissection 1) :—

Dissection 1.

Number dissected	Stage of the ovary	Pupal structures
45	23—N.	Present
	21—I.	,,
	1—I-II.	,,

Note : N = Follicles consist of undifferentiated cells.
I = Ovum differentiated, no yolk granules.
I–II = Deposition of the first yolk granules.
II = Stage II of Christophers; the plasma of the ovum is covered with yolk granules; the ovum occupies a third of the follicles.

It seems that there is a correlation between the size of the insect and the state of the development of the ovary, the larger females having the ovaries at a later stage than the smaller (Dissection 2).

Dissection 2.

	Number dissected	Ovaries
Large females*	14	N—2, I—11, I–II—1
Small ,, ...	31	N—21, I—10, I–II—0

If the newly emerged females are kept without food and water, the pupal remains are slowly resorbed and the brownish mass is passed out through the hindgut ; this process is completed within the first 24 hours. At the same time the ovary increases in size and single follicles show further development. The rate of this early development depends on the temperature, but without feeding it never goes beyond Stage II of Christophers.

Females were collected immediately after emergence, placed (*a*) in the incubator, (*b*) in the ice-chest, and dissected after 24 and 48 hours, small insects being used (Dissection 3).

Dissection 3.

	Stage of the ovaries		
Incubator. T.24°C. at night, 30°C. in the day-time :—			
Dissected after 24 hours	I—10	I–II—1	II—0
,, ,, 48 ,, ...	—4	—4	—0

	Stage of the ovaries			
Ice-chest. T. 12°–14°C. :—				
Dissected after 24 hours	N—6	I—0	I–II—0	II–0
,, ,, 48 ,, ...	—6	—4	I–10—0	—0

It is probable that this early ovarian development occurs at the expense of the reserve accumulated during the larval life, the traces of fat found in every newly-emerged *Anopheles* female being consumed during this early period of the life of the imago.

If freshly emerged females of various sizes are kept for standard times in the incubator or in the ice-chest—36 hours and 5 days, respectively—it is found on dissection of their ovaries that the stage to which the ovaries have developed during this period depends on the season and on the size of the female, and therefore on the conditions of the larval life (Dissections 4 and 5).

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*In this work the size of the females was determined by measuring the length of the thorax in units equal to 1/16 mm. Large females consisted of those having a thorax of 27 to 31 units long ; the small ones were 23 to 26 units long.

Dissection 4.

Dissection of *Anopheles* females of the summer generations (May–September).

	Number dissected	Stage of the ovaries			
		II	I–II	I	N
After 36 hours in incubator, T. 27–30°C. :—					
Large females	21	17	4	0	0
Small ,, ...	62	12	21	29	0
After 5 days in ice-chest, T. 14°C. :—					
Large females	19	5	14	0	0
Small ,, ...	56	3	15	36	0

Dissection 5.

Dissection of females of the hibernating generation which were bred from the eggs laid by the last egg-laying females in October ; they emerged during November and the first half of December ; in other words they spent their aquatic life at a temperature ranging between 8·5°C. and 23°C.

	Number dissected	Stage of the ovaries			
		II	I–II	I	N
After 36 hours in incubator, T. 27–30°C. :—					
Large females	40	4	17	19	0
Small ,, ...	32	0	2	29	1
After 5 days in ice-chest, T. 14°C. :—					
Large females	57	0	32	25	0
Small ,, ...	16	0	5	11	0

It appears, therefore (Dissections 4 and 5), that in females of the hibernating generation the initial development of the ovary is impaired. In other words, the tendency to hibernate manifests itself from the very beginning of the ovarian development and cannot be completely abolished by keeping the mosquitos at a summer temperature.

It seems logical to assume that hibernation was predetermined by some change in the aquatic stages of the mosquito. The stage in the life of the mosquito that is sensitive to the impairing factor was next investigated.

Pupae which were bred in the open in November–December at temperatures ranging between 8·5°C. and 23·5°C. (as in Dissection 5), were transferred within two hours after the pupation to the incubator (T. 24–40°C.). The females which emerged from these pupae were kept for 36 hours at 24–30°C., as before, and then dissected (Dissection 6).

Dissection 6.

	Number dissected	Stage of the ovaries			
		II	I–II	I	N
After 36 hours at 24–30°C. :—					
Large females	8	5	3	0	0
Small ,, ...	17	4	9	4	0

Similar results were obtained when eggs laid by the last egg-laying females in October were bred at 24–30° up to the emergence of the mosquitos and the females kept during 36 hours at the same temperature.

	Number dissected	Stage of the ovaries			
		II	I–II	I	N
Large females	7	4	3	0	0
Large ,, ...	22	10	8	4	0

It is clear, therefore, that if the aquatic stages of the hibernating generation of *A. elutus* are exposed to high temperatures the adult female behaves with respect to the initial development of the ovaries more or less as a summer insect.

Development of the Ovary after a Blood Feed.

Newly emerged *A. elutus* females collected during the summer were fed on human beings within the first 24 hours after their emergence. Those that had a full feed were divided into two lots: one being kept at 23–30°C., the other at 14°C. All of them were dissected when digestion had been completed (Dissections 7 and 7a).

Dissections 7 *and* 7*a*.

	Number dissected	Stage of the ovaries		
		Ripe eggs	II	Below II
Incubator :—				
Large females	14	3	10	1
Small ,, ...	39	3	23	13
Ice-chest :—				
Large females	17	5	7	5
Small ,, ...	59	5	26	28

Ripe eggs were formed in only a small number of the newly emerged females after one feed of blood, this number being proportionately greater in larger than in the smaller females. Moreover, in practically all the larger females of the incubator group in which mature eggs did not form the ovaries developed to stage II. In the small females, although a smaller number contained ovaries at stage II, the proportion is larger than would have been expected if no food had been taken.

Some of the small females which were kept in the ice-chest and in which the eggs had not matured after the first blood feed, were again fed on blood and were kept in the ice-chest (Dissection 8).

Dissection 8.

	Number dissected	Stage of the ovaries		
		Ripe eggs	II	Below II
Ice-chest :—				
Small females	25	11	14	0

After the second blood feed the number of insects in which ripe eggs were found is higher than after the first feed ; and in all those in which no ripe eggs were found the ovaries were in stage II. The number of females which have mature eggs after the second feed corresponds roughly to the number which would have been expected to develop the ovaries to stage II after the first feed.

Similar experiments were carried out with hibernating females. The results were quite different. Females which emerged in November and December were fed during the first 24 hours after emergence and placed in the ice-chest at 14°C. The mosquitos were dissected after the blood was digested (Dissection 9).

Dissection 9.

	Number dissected	Stage of the ovaries		
		Ripe eggs	II	Below II
Ice-chest :—				
Large females	25	0	11	14
Small „	20	0	6	14

In none of these mosquitos did the eggs mature after a single blood feed, and in more than half the number the ovaries did not develop to stage II.

If a blood feed, however, is given the development of the ovaries is better than it would have been under the same conditions without any food (see Dissection 5).

Development of Ovaries after Feeding with Raisins and Blood.

Hecht has found that feeding on sugar stimulates egg maturation in *A. maculipennis* which had previously fed on blood. In *A. elutus* we find that the eggs do not mature when the mosquitos are fed on raisins only, but they accumulate a certain amount of fat and the ovaries develop up to stage II.

The results obtained with newly emerged females, when fed on raisins during seven days and kept at 24–25°C., are given below (Dissection 10).

Dissection 10.

	Number dissected	State of the ovaries			
		Ripe eggs	II	I–II	I
Large females	10	0	10	0	0
Small „	39	0	34	5	0

Some of these females, after having been fed on raisins for seven days, were fed on blood and kept at 14°C. The quantity of blood ingested was necessarily very small because of the distension of the diverticulum by the raisin juice. On dissection after the blood was digested it was found that in the females fed on raisins mature eggs were formed in practically all cases after one blood feed, irrespective of the size of the female (Dissection 11).

Dissection 11.

	Number dissected	Stage of the ovaries		
		Ripe eggs	II	Below II
Large females	8	8	0	0
Small „	18	17	1	0

These results differ from those obtained with one blood feed without previously feeding on raisins (see Dissections 7 and 7a). The question therefore arises : What function does the raisin fulfil in the process of egg maturation ? The following series of experiments were carried out in order to make this point clear.

A. elutus females (small size) were fed on raisins during the first day after emergence. As soon as the diverticulum was distended with the raisin juice, they were transferred into clean cages and kept without any food at a temperature of 24–25°C. Various batches were fed with blood at different intervals after the raisin feed ; a portion of each batch was dissected immediately after blood-feeding as a control and the remaining females of the batch were dissected after digestion of the blood.

	Control Stage of ovaries				Experiment Stage of ovaries			
	Ripe eggs	II	I–II	I	Ripe eggs	II	I–II	I
Small newly emerged females; no feed at all. Dissected 12 hours after emergence	0	0	14	18				
Small newly emerged females; no raisins; blood feed during first 12 hours after emergence. Dissected after digestion					0	28	4	0
Raisin feed followed by blood feed after 8 to 12 hours. Dissected after digestion					8	10	0	0
Raisin feed followed by blood feed after 24 hours:—								
Control: dissected immediately after blood feed	0	0	10	0				
Experiment: dissected after digestion					16	14	0	0
Raisin feed followed by blood feed after 48 hours:—								
Control: dissected immediately after blood feed	0	7	5	0				
Experiment: dissected after digestion					14	1	0	0
Raisin feed followed by blood feed after 72 hours:—								
Control: dissected immediately after blood feed	0	11	2	0				
Experiment: dissected after digestion					18	1	0	0

The order of feeding was then reversed: the blood feed was given first, the raisin feed following.

	Stage of ovaries		
	Ripe eggs	II	I–II
Blood feed; after digestion the females were fed on raisins for 7 days	0	13	4
Blood feed; followed by raisin feed before the digestion of blood was complete (2nd day)	1	9	0
Two blood feeds consecutively	12	10	2

It is apparent, therefore, that the raisin feeding brings the ovary development to the stage II, and that only after it reaches this stage can a single blood feed lead to ripening of the eggs. No eggs can ripen on raisins only, and no eggs can ripen on one blood feed unless the ovaries have reached stage II of their development before the blood is digested.

Discussion.

These experiments were carried out with *A. elutus* females bred in the laboratory and therefore not fecundated. Under natural conditions, when all the females become fecundated sooner or later during their imago life, conditions may be different. It seems certain, however, that while fecundation stimulates egg-laying it does not influence egg maturation.

Some of our observations on wild *A. elutus* females agree with our laboratory findings and strengthen the supposition that the findings in the laboratory are true also in nature. These observations will be published elsewhere, but may be briefly summarized here :—

1. In multiparous *A. elutus* females the ovaries are always at stage II after laying and, with few exceptions, a new set of eggs is formed with one blood feed.

2. Nulliparous females are very often found with the diverticulum distended with some juice of unknown nature, indicating that some plant food has been taken before the blood feed.

3. During the summer months one rarely finds nulliparous *A. elutus* females with the gut full of freshly ingested blood and the ovary below stage II, while at the beginning of hibernation this condition is found regularly.

4. The temperature of the breeding-places at the beginning of the hibernation period (at the end of October 1934) was the same as that at the end of March and April, 1935, and it is a fact that the first spring generation of *Anopheles* still exhibits to a certain extent the gonotrophic dissociation characteristic of hibernating mosquitoes.

5. Hibernating *A. elutus* females born in November and the first half of December have been found breeding at a temperature lower than that of April or even March.

Conclusions.

1. There are two successive well-defined stages in the development of the ovary in the newly-emerged *A. elutus* female : (*a*) the development of the follicle up to stage II ; (*b*) further maturation of the egg.

2. Development up to stage II can be achieved either at the expense of the reserves accumulated during aquatic life or by feeding on blood and raisins.

3. In mosquitos of the spring and summer broods only in large females will the ovary develop up to stage II without feeding. This suggests a connection between the development of the ovary and the nutritional conditions during larval life.

4. The maturing of the eggs after the ovary has reached stage II occurs only after ingestion of blood. The number of feeds of blood needed to produce mature eggs depends on the state of the ovary at the time of blood ingestion. In *A. elutus* females whose ovaries are at stage II at the time of blood ingestion the eggs mature after one blood feed independently of the temperature and of the size of the mosquitos.

5. In hibernating females the process of development of the ovaries to stage II is impaired ; this impairment does not occur if all aquatic stages or if the pupae alone are bred at higher temperatures.

6. It is suggested that the inability of the ovary to develop to stage II without food and the slow rate of the development at the then prevailing low temperature are factors producing the so-called semi-hibernation state of *A. elutus* in Palestine.

References.

CHRISTOPHERS, Sir S. R., & SINTON, J. A. (1931). How to do a Malaria Survey.—Health Bull. no. 14.

HECHT, O. (1933). Experimentelle Beitraege zur Biologie der Stechmuecken IV.—Arch. Schiffs- u. Tropen. Hyg., **37,** pp. 256-271.

——. (1933). Die Blutnahrung, die Erzeugung der Eier und die Ueberwinterung der Stechmueckenweibchen.—Beih. Arch. Schiffs- u. Tropen. Hyg., **37,** pp. 125-211.

A LIST OF THE TERMITES OF TANGANYIKA TERRITORY, WITH DESCRIPTIONS OF TWO NEW SPECIES.

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As a basis for further work on the biology of termites, the need for which is now being generally recognized in view of the importance of this group of insects as pests in all tropical countries, the present list of the termites of Tanganyika Territory has been prepared. It incorporates the results so far obtained from the examination of a collection made by the writer during the past three years in a number of widely separated localities in Tanganyika, with the records given by Sjöstedt (1926). Previous records have been mainly from the Kilimanjaro-Usambara area in the extreme north-east of the Territory.

The number of species listed here is 51. Of the 26 species recorded by the writer 10 are new to Tanganyika and two are described as new species (*Allodontermes morogorensis* and *Basidentitermes amicus*). The genera *Microtermes* and *Cubitermes* are represented in the collection by a number of forms not yet fully worked out, and in any consideration of the status of these genera in the termite fauna as a whole, it may be assumed with safety that the number of species is greater than is listed here.

The new records, on the whole, fill in gaps in the distribution of species known from other parts of the eastern and southern Savannah zone, or extend eastwards forms known from the drier parts of the Belgian Congo. *Basidentitermes amicus*, sp. n., is of interest in that it extends greatly the range of this genus, as given by Emerson (1928, map 20). For a general discussion of the geographical distribution of African termites and their relation to the fauna of other regions, reference should be made to Emerson (*l.c.*).

For details regarding previous records from Tanganyika, the work of Sjöstedt, from which they have been compiled, should be consulted. The nomenclature of this authority has been followed throughout, and I would like to express my appreciation of the work that Professor Y. Sjöstedt has done on the systematics of African termites, without which the present study would not have been possible.

Extensive bibliographies are given in the works of Sjöstedt and Emerson cited above.

The following brief notes will aid in identifying the localities in which specimens have been obtained :—

Morogoro—on the Central Railway, 150 miles from the coast and 500 metres above sea-level.

Uluguru—a block of mountains immediately south of Morogoro.

Igalula—a village on the railway 25 miles east of Tabora.

Kigoma—on Lake Tanganyika, terminus of the railway.

Uvinza—a village 50 miles east of Kigoma.

Kasulu—north-east of Kigoma, in mountainous country on the borders of Ruanda-Urundi.

Kipili and Kirando—on the lake, south of Kigoma.

Kalambo River—at the south end of Lake Tanganyika.

Ufipa—a plateau, 1,500 to 2,000 metres, east of the southern part of Lake Tanganyika.

Rukwa—the Rift Valley east of Ufipa.

Mwanza—on the southern shores of Lake Victoria.

Kahama—south of Mwanza, half-way to Tabora.

Iringa—in south-central Tanganyika, 7·45′S. 35·30′E., elevation 1,500 metres.

Songea—in the south-west, on the plateau east of Lake Nyasa.

Finally, I wish to thank Professor A. D. Hobson for the facilities afforded me for carrying out this work at Armstrong College, Durham University, and Mr. J. Omer-Cooper for much helpful advice and criticism.

Family HODOTERMITIDAE.

The members of this family are widely distributed throughout the drier parts of Africa. The single species known from Tanganyika ranges from the Cape to Abyssinia.

1. *Hodotermes mossambicus*, Hagen.

Shinyanga, iv.34, cutting cotton foliage.

Kahama, v.35, cutting pasture grasses.

Usambara, 34, in stomachs of a weaver, *Ploceus castaneiceps*, and a nightjar (A. E. Moreau.)

(Sjöstedt : Lake Manyara, Tanga, Usambara, Kilimanjaro neighbourhood.)

Family CALOTERMITIDAE.

This family includes the " dry wood termites " and most of them live in hard wood without any connection with the ground. The African species do not appear to be of such economic importance as in other parts. The three species recorded from Tanganyika are not represented in the present collection.

2. *Calotermes jeannelanus*, Sjöst. (Sjöstedt : Kilimanjaro.)
3. *Neotermes cryptops*, Sjöst. (Sjöstedt : Ugalla, Ituri ferry.)
4. *Neotermes meruensis*, Sjöst. (Sjöstedt : Mt. Meru neighbourhood.)

Family RHINOTERMITIDAE.

Three species of this tropicopolitan family are recorded here. Though living in tree-trunks and timber, often at a considerable height above ground, the colonies nevertheless maintain connection with a subterranean nest.

5. *Schedorhinotermes lamanianus*, Sjöst.

Pangani, ix.34, in the wood of a hollow *Poinciana regia.*

Morogoro, ii.35, in branch of avocado (*Persea*) ; colonial nest with fungus garden.

Tanga, iii.35, in tunnels on the trunks of Ceara rubber (*Manihot glaziovii*).

(Sjöstedt : Usambara, Mombo.)

6. *Coptotermes amanii*, Sjöst.

Amani, ix.34, in old building timber.

Morogoro, xii.33, in dead branch on ground, in association with *Termes* sp. ; viii.34, in timbers of native hut ; iv.35, in earthen tunnels on trunk of *Pithecolobium*, together with *Microtermes* sp. and *Microcerotermes* sp.

(Sjöstedt : Amani, Moshi, Dar es Salaam.)

7. *Coptotermes sjöstedti*, Holmgren.

(Sjöstedt : Kawendi, Kalui Plain.)

Family Termitidae.

This is the most important family of termites in Africa, both in number of species and from the economic aspect. Almost all are subterranean in habit, and many build mounds of various shapes and sizes. They cultivate fungus gardens.

8. *Pseudacanthotermes militaris*, Hagen.

Morogoro, iv.34, making earth tunnels on the stems of living trees and shrubs, but not apparently injurious.

Usambara, Muhesa, ix.34, nests located during excavations ; also in fallen tree.

Kigoma, xii.34, attacking bamboo fence ; issuing from small holes in open grassland, and living in part of a mound built by *Bellicositermes bellicosus*.

(Sjöstedt : " Tanganyika Territory.")

9. *Pseudacanthotermes spiniger*, Sjöst.

Kigoma, xii.34, building new portion to a mound of *B. bellicosus*.

Kasulu, i.35, building small mounds ; winged imagines eaten by local natives.

10. *Bellicositermes goliath*, Sjöst.

Morogoro, vii.34, from large mound in a kapok plantation ; also from tunnels on bark of adjoining trees.

Iringa, viii.34, large mound builders.

Uvinza, vii.34, rounded mounds in red soil.

Rukwa, xi.33, large mounds numerous on plain near lake.

Ufipa, Sumbawanga, xi.33, large mounds common on open plateau.

(Sjöstedt : Kilimanjaro, Usambara, Tanga, Massai, Mkaramo, Dar es Salaam.)

11. *Bellicositermes bellicosus*, Smeath.

Morogoro, common ; mounds absent or small ; fungus comb of large dimensions ; sheet-like earth runs common on tree trunks.

Uzinza, x.34.

Kahama, viii.34, building high conical nests.

Kasulu, i.35.

Kigoma, xii.34, common ; building medium-sized mounds, most of which are occupied in part by *Pseudacanthotermes* spp. and *Microtermes* spp.

Songea, iii.35, common ; building large rounded or conical mounds ; also attacking tobacco stalks.

(Sjöstedt : Kilimanjaro, Meru, Usambara, Tanga, Useguha, Karema, Lake Tanganyika.

12. *Bellicositermes natalensis*, Hav.

Usambara, Muhesa, ix.34, subterranean nest, workers in fallen tree-trunk.

Kalambo River, x.33, building large mound.

Mwanza, iv.34, attacking stems of mature maize.

13. *Termes badius*, Hav.

Morogoro, common ; subterranean nests with large air-shafts.

Uluguru, i.35.

Amani, ix.34, appearing through timber work of dwelling house ; also in fallen tree.

Iringa, viii.34, building mounds up to 4 feet in height and 8 feet in diameter.

Songea, iii.35, from rounded mounds.

(Sjöstedt : Kilimanjaro, Tanga.)

14. *Termes latericus*, Hav.

Kipili, x.33, from earth runs in areas where much grass had been destroyed, apparently by this termite.

Uluguru, i.35, nest under a large boulder on steep hill slope.

15. *Termes tanganicus*, Sjöst.

Uluguru, i.35.

(Sjöstedt : Tanga.)

16. *Termes monodon*, Gerst. (Sjöstedt : Useguha, Mpwapwa.)
17. *Termes amanicus*, Sjöst. (Sjöstedt : Amani.)
18. *Termes amaniensis*, Sjöst. (Sjöstedt : Amani.)
19. *Termes culturarum*, Sjöst. (Sjöstedt : Myombo.)
20. *Termes stercorivorus*, Sjöst. (Sjöstedt : Kilimanjaro.)
21. *Termes microps*, Sjöst. (Sjöstedt : Kilimanjaro, Tanga.)
22. *Termes ramulosus*, Sjöst. (Sjöstedt : Kondoa.)
23. *Termes palmquisti*, Sjöst. (Sjöstedt : Kilimanjaro.)
24. *Allodontermes morogorensis*, sp. n.

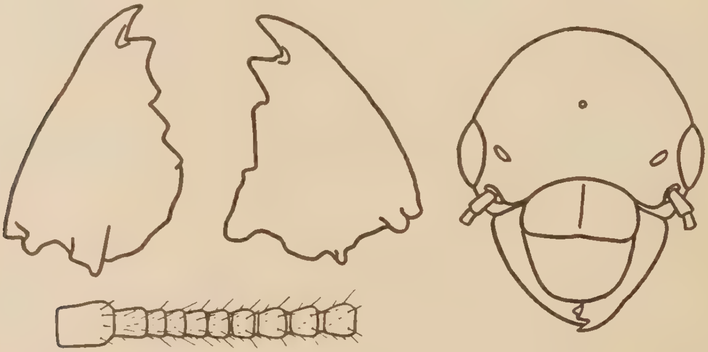

Fig. 1. *Allodontermes morogorensis*, sp. n., imago ; head, mandibles and antenna (part).

Imago.—Head round, dark brown with numerous less densely-pigmented spots from which arise short pale hairs. Clypeus prominent, paler in colour. Fontanelle small. Ocelli oval. Antennae with 19 segments, dark brown, the basal segment longest, 2 slightly longer than co-equal 3, 4 and 5. Labrum lightly pigmented, with hyaline tip. Anterior border of pronotum practically straight, with very slight median notch and rounded corners ; sides converging to posterior border, which has more definite median notch. Wings pale brown, with slightly darker veins. Legs brown, the femora darker than tarsi and tibiae. Sclerites of thorax and abdomen dark brown, in strong contrast with white intersegmental membrane.

Length with wings	21·0 mm.	
Length without wings	10·6 mm.	
Length of head to anterior border of clypeus	1·52 mm.	
Width of head, including eyes	1·76 mm.	
Diameter	0·50 mm.	
Width of pronotum	1·58 mm.	(1·63, cotype)
Length of anterior wing	18·0 mm.	
Width of anterior wing	4·25 mm.	

A. infundibuli has a shorter wing (15·0 mm.) and circular ocelli, while *A. schultzei* has a longer wing (19·0 mm.) and a paler body.

Soldier.—Head with sides parallel, posterior widely rounded, light yellow. Antennae with 17 segments, 2 to 6 being in the following proportions : 16, 7, 10, 10 and 12. Labrum broadly rounded, with pointed hyaline tip and bearing a number (usually six) of fine hairs. Mandibles robust, dark brown except for yellow bases ; left mandible deeply serrated, with large basal tooth ; right with single tooth approximately half-way down, the rest smooth. Pronotum narrower than the head, anterior border rounded with deep median notch, posterior border more widely rounded with smaller notch ; length to breadth as 7/10.

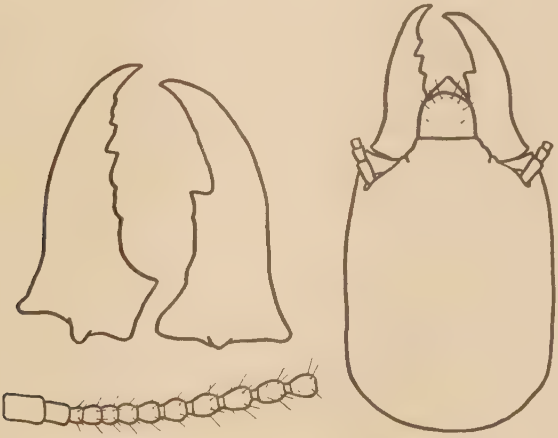

Fig. 2. *Allodontermes morogorensis*, sp. n., soldier ; head, mandibles and antenna (part).

Length of head and mandibles	2·51 mm.	(2·50–2·57).
Length of head to base of labrum	1·65 mm.	(1·62–1·67).
Width of head	1·17 mm.	(1·17–1·20).
Length of pronotum	0·62 mm.	
Width of pronotum	0·89 mm.	
Length of left mandible	0·87 mm.	(0·85–0·87).

Very close to *A. infundibuli*, Sjöst., but with longer head and mandibles than those described.

Major Worker.—Head rectangular, rounded posteriorly ; tan brown. Clypeus paler, with dark median line. Labrum large, projecting past tip of closed mandibles, lightly pigmented. Antennae 17-segmented, basal segment largest, 2 larger than 4 or 5, 3 smallest.

Length of head to tip of labrum	1·58 mm.
Width of head	1·20 mm.

Minor Worker.—Similar to major worker, except that the head is more rounded and the sides converge posteriorly.

Length of head to tip of labrum	1·15 mm.
Width of head	0·92 mm.

Localities.—Morogoro, 2, xii.34 (type) ; winged imagines issuing in great numbers from small funnel-shaped exit-holes on paths and bare pieces of ground during early evening ; soldiers and workers present. Soldiers and workers commonly found attacking trees and lawns.

Tanga, on coconut palms.

Mwanza and Tabora, on *Cassia* trees.

Biology.—An earth-nesting termite widely distributed in Tanganyika. Of some importance as a pest, more particularly during drought. The soldiers exude considerable quantities of sticky fluid when disturbed. Types in the British Museum.

25. *Microtermes redenianus*, Sjöst.

    Morogoro, ii.35, winged imagines emerging from subterranean nests ; soldiers exude much fluid when disturbed.

    (Sjöstedt : Tanga.)

26. *Microtermes usambaricus*, Sjöst. (Sjöstedt : Usambara, Mombo.)

27. *Microtermes vadschagge*, Sjöst. (Sjöstedt : Kilimanjaro.)

28. *Microtermes magnocellus*, Sjöst. (Sjöstedt : Tanga.)

29. *Hamitermes unidentatus*, Wasm.

    Uvinza, xi.34, occupying part of a mound apparently built by *Cubitermes* sp., but also containing *Trinervitermes* sp. and *Microcerotermes* sp.

    Kirando, x.33, from a low mound under dense tree shade.

    Tabora, v.35, building irregular mounds up to two feet high in black soil of seasonal swamps ; absent from red soils.

30. *Hamitermes meruensis*, Sjöst. (Sjöstedt : Kilimanjaro, Mt. Meru.)

31. *Hamitermes hastatus*, Hav. (Sjöstedt : Kilimanjaro.)

32. *Microcerotermes parvus*, Hav.

    Morogoro, commonly found in small earthern tunnels on the bark of trees ; also tunnels in stems of perennial cotton.

    Uluguru, xi.34, in fallen tree-trunks in forest.

    Usambara, Muhesa, ix.34, in dead rubber tree.

    (Sjöstedt : Kilimanjaro.)

33. *Microcerotermes zuluensis*, Hgrn.

    Kalambo River, x.33, building small domed mounds in *Brachystegia* woodland.

    (Sjöstedt : Morogoro.)

34. *Microcerotermes edentatus*, Wasm.

    Kigoma, xii.34, arboreal nests in branches of mango trees.

35. *Microcerotermes parvulus*, Sjöst.

Uluguru, ii.35, nests just below surface of ground and in shelter of large rocks. Interior of nest very hard and black.

36. *Cubitermes bilobatus*, Hav.

Igalula, xii.34, building large dark-coloured dome-mounds, although surface soil red ; in *Brachystegia* woodland. Mounds also containing *Trinervitermes* sp. and *Microcerotermes* sp.

(Sjöstedt : Mt. Meru.)

37. *Cubitermes glebae*, Sjöst. (Sjöstedt : Kilimanjaro.)

38. *Noditermes indoensis*, Sjöst.

Kasulu, i.35, from small, hard, round or conical mounds in lateritic ironstone soil.

39. *Ophiotermes massaicus*, Sjöst. (Sjöstedt : Kilimanjaro.)

40. *Basidentitermes amicus*, sp. n.

Soldier.—Head pale red-brown ; sides parallel for the greater part, converging anterior to the antennae ; posterior rounded. Frontal area sloping sharply. Fontanelle large, surrounded by hairs. Labrum large, sides curved, anterior margin with pointed corners and moderately convex median lobe bearing three pairs of slender bristles. Mandibles long, slender, dark-coloured ; the left with acute notch near base on inner face. Antennae doubtfully 14-segmented (type specimen has one antennae with 13 segments, obviously incomplete, while the other is complete with 13, but segment 3 is so large as to suggest fusion of 3 and 4). Gulamentum does not project downwards when head is viewed in profile. Anterior border of pronotum lightly emarginate. Thorax and abdomen pale with numerous short hairs.

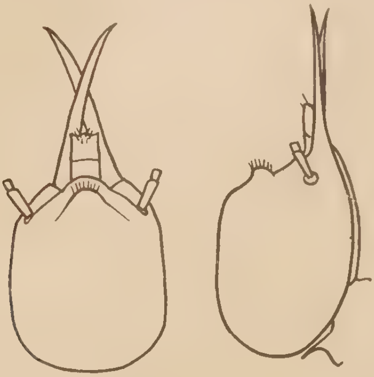

Fig. 3. *Basidentitermes amicus*, sp. n. Head of soldier.

Total length	4·70 mm.
Length of head and mandibles	3·22 mm.
Length of head	1·70 mm.
Width of head	1·46 mm.
Length of left mandible	1·58 mm.
Length of antenna	2·11 mm.
Length of pronotum	0·28 mm.
Width of pronotum	0·71 mm.

Smaller than *B. malelaensis*, Emers., from which it also differs slightly in shape of labrum.

Locality.—Songea, iii.35 (type); described from a single specimen found in a tube of *Eutermes latifrons*, Sjöst., collected from a nest just below the surface of a mound made by *Termes badius*, Hav.

Type in the British Museum.

41. *Promirotermes bellicosi*, Wasm. (Sjöstedt: Kilimanjaro.)

42. *Eutermes latifrons*, Sjöst.
Songea, iii.35, from nest in mound of *Termes badius*.

43. *Eutermes usambarensis*, Sjöst. (Sjöstedt: Usambara.)

44. *Eutermes kilimandjaricus*, Sjöst. (Sjöstedt: Kilimanjaro.)

45. *Trinervitermes segelli*, Sjöst.
Uluguru, xi.34, making heaps of soil two inches high on a lawn.
Kigoma, xii.34, making dome-mounds up to 2½ feet high.
(Sjöstedt: Kilimanjaro, Meru, Dar es Salaam.)

46. *Trinervitermes gratiosus*, Sjöst.
Uvinza, xii.34, numerous dome-mounds up to 2½ feet high, with very hard surface; also found swarming on grasses, eating dead vegetation, one humid evening.

47. *Trinervitermes bettonianus*, Sjöst.
Uvinza, xii.34, small mounds up to 8 in. high in red soil.
(Sjöstedt: Usambara, Kihuhui.)

48. *Trinervitermes gemellus*, Sjöst. (Sjöstedt: Mt. Meru.)

49. *Trinervitermes ruficeps*, Hgrn. (Sjöstedt: Amani.)

50. *Trinervitermes rapulum*, Sjöst. (Sjöstedt: Tanga.)

51. *Coarctotermes coarctatus*, Sjöst.
Morogoro, xii.34, winged imagines emerging from subterranean nests; soldiers and workers present.

References.

SJÖSTEDT, Y. (1926). Revision der Termiten Afrikas.—K. Svensk. Vetens Akad Handl., 3, No. 1.

EMERSON, A. E. (1928). Termites of Belgian Congo and Cameroon.—Bull. Amer. Nat. Hist. Mus., **57.**

ON THE FIRST INSTAR LARVAE OF SOME SPECIES OF *OTIORRHYNCHUS* FOUND ON STRAWBERRIES, WITH NOTES ON THEIR BIOLOGY.

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Introduction.

The damage done to strawberries by certain Otiorrhynchid weevils in both the larval and the adult stages is well known, and the importance of recognising these species with certainty, even in their earliest stages, will be recognised. Up to the present time a number of papers have been published on the full-grown larvae, but workers in this field have found that many of the characters so described are difficult to detect or even missing in the first instar larvae.

The present investigation was therefore undertaken to discover some practical means of identification of these newly-hatched larvae of the species *Otiorrhynchus* (*Brachyrhinus*) *sulcatus*, Fabr., *O. rugosostriatus*, Goeze, *O. ovatus*, Linn., and *O. rugifrons*, Gyll. The last species was included in the study although it has been recorded as attacking strawberries less often than the others ; but it is so nearly related to *O. sulcatus* in both food and habits that it seems probable that large infestations may sometimes occur.

Owing to the minute size of the larvae in this stage (about 1·5 mm. long) the technique of studying the morphology was to stain and mount as microscope slides specimens which had been boiled in caustic potash, compressing the empty skin so formed dorso-ventrally. In certain cases the mouth-parts were dissected out and mounted separately.

It must be realised, of course, that all the characters described in this study are liable to slight variations. A number of individuals of each species were examined, and those characters which appeared to vary widely were not included in the descriptions. In the case of *O. rugifrons* only two specimens were, however, available for this work. It is unfortunate that nearly all the characters that were found to be valuable were those of the chaetotaxy ; these are not nearly as easy to use for identification purposes as are obvious differences in the mouth-parts, etc. These latter organs were, however, studied with great care, but no notable dissimilarities were discovered between the four species.

In addition to the morphology, notes are appended on the biology of the four species. These were compiled partly from the writer's own observations and partly from the very scattered literature.

The material was collected by the writer in the summer of 1935 at the Hampshire County Council Experimental Fruit Station, Botley, with the kind help of Mr. W. E. H. Hodson and Mr. D. O. Boyd, of Reading University. The writer is also considerably indebted to Mr. A. W. Rymer Roberts, of the Molteno Research Institute, Cambridge, for specimens of *O. rugifrons*, as well as for much information and useful criticisms of the typescript. These specimens of *O. rugifrons* were originally taken by Mr. G. Fox-Wilson, of Wisley.

Morphology.

The general morphology of the weevil larva has been fully described by both Rymer Roberts[8] and Keifer[7], the latter writer dealing with the above-mentioned species (except for *O. rugifrons*) only in a fully-grown state. The following study is therefore confined to the points on which the first instar larvae differ either from each other or from those characters described by Keifer for the more mature larvae. In regard to the length of the setae, five types are recognised in the ensuing descriptions—namely, very large, large, medium, small and minute. These divisions are, of course, quite arbitrary, but in actual length may be assumed to be as follows: Very large, more than 120μ; large, 120–70μ; medium, 70–30μ; small, 30–10μ; minute, less than 10μ.

Head-capsule.

The form of the head-capsule is shown in fig. 1, the setae being named after those described by Keifer. It will be noticed that the one illustrated, that of *O. sulcatus*, has a frontal suture (*fs.*) which does not extend right forward to the base of the mandibles, as in later instars; in the other three species this suture seems to be even shorter and less well marked. The general plan of the setae does not differ greatly from that on the more mature larvae, but the minute setae, *e.g.*, *sm.*2, were too small to be located, if they were present at all. The relative position of the macro-setae in the first instar appears to differ slightly in the four species. Thus it will be noted from fig. 1 that a line drawn through the setae *sl.*2., *sm.*3., and *adm.* of the right and left sides, is practically straight. With *O. rugosostriatus* on the other hand, this line is bent at the epicranial suture, so that the lateral ends are more anterior; with *O. ovatus* the arrangement is similar to this, but the seta *sm.*3. is rather posterior to the line, as in *O. rugifrons*.

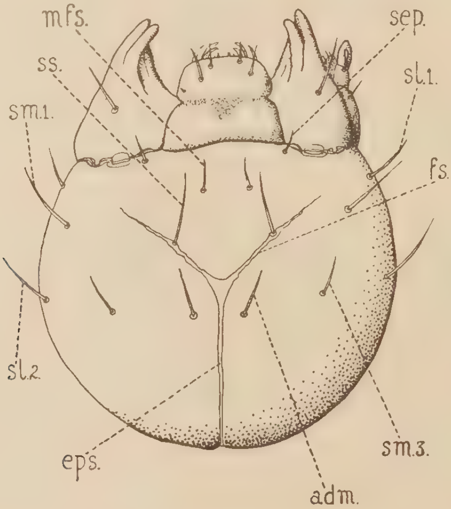

Fig. 1. *Otiorrhynchus sulcatus*, dorsal aspect of head (× 117); *adm*, admedian epicranial seta; *mfs*, admedian frontal seta; *sl.*1, *sl.*2, sublateral setae; *sm.*1, *sm.*3, submedian epicranial setae; *eps*, epicranial suture; *sep*, lateral epistomal seta; *ss*, sutural seta; *fs*, frontal suture.

Another slight difference is the position of the seta *sm.*1. In both *O. rugifrons* and *O. ovatus* this seta lies almost on a line between setae *ss.* and *sl.*1. *O. rugosostriatus* differs, however, in having this seta in a position almost directly posterior to the seta *sl.*1.

Labrum and Clypeus.

There appear to be considerable differences in the shape of the labrum which have not been described by previous writers; these are illustrated in fig. 2 for the four species.

In general the shapes are dissimilar, that of *O. rugosostriatus* (A) being rounded laterally and not produced anteriorly as much as in the other three ; in *O. ovatus* (B) the labrum is more straight-sided ; in *O. sulcatus* (C) it is wider posteriorly, the lateral angles being rather well-marked ; the labrum of *O. rugifrons* (D) is similar to this, but the sides are more rounded. Down the lateral edges of the labrum of *O. ovatus* are three short tooth-like ridges, as shown in the figure, while in *O. sulcatus* there are four thin lines in this position, possibly being vestiges of these processes. In the other two species this character appears to be wanting.

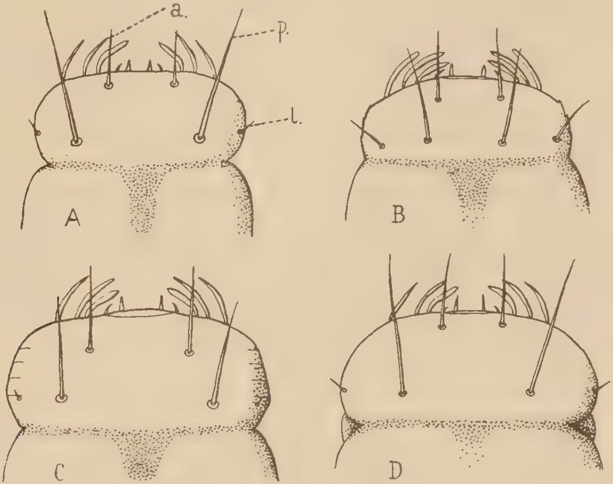

Fig. 2. Dorsal aspect of labrum and clypeus of A, *O. rugosostriatus* ; B, *O. ovatus* ; C, *O. sulcatus* ; D, *O. rugifrons* ; (×375). *a*, anterior seta ; *p*, posterior seta ; *l*, lateral seta.

The position of the setae on the upper side of the labrum also furnishes an excellent character. Of these there are three pairs, an anterior, a posterior, and a lateral pair ; these last are of medium size in *O. ovatus*, small in *O. rugosostriatus* and *O. rugifrons*, and minute in *O. sulcatus*. The anterior pair of setae are usually of medium size and situated near the median line. In *O. sulcatus*, however, they are widely separated and in *O. rugosostriatus* they are rather smaller. The posterior setae also vary in a similar manner, being widely separated in all species except *O. ovatus* ; also these setae are large in *O. rugosostriatus* and *O. rugifrons*, but only of medium size in the other two species.

The lower side of the labrum and clypeus, forming the epipharynx was also examined, but the variations figured by Barrett[1] for the final instar were not found to be so marked in the first instar. The other mouth-parts were also closely examined, but no notable differences were found.

Thorax.

The dorsum of the prothorax is in the form of a chitinous shield, while that of the meso- and metathorax is divided into three folds, namely, the prescutum, the scuto-scutellum, and the postscutum. On these are approximately regular patterns of setae.

Keifer counts the dorsal setae outwards from the mid-dorsal line, numbering them I, II, III, IV, etc. ; thus there are said to be usually four setae on the meso- and metascuto-scutellum—*i.e.*, four on each side and eight all together ; there is also one seta on each side on the prescutum of the meso- and metathorax.

This worker has also shown that the length of the setae on the meta-scuto-scutellum differ somewhat in the three species he studied, and the present writer has found that this also holds true for the first instar larvae. Thus seta I is small in all species studied except *O. ovatus* ; II is large in *O. sulcatus* and *O. rugosostriatus*, but small in the other two species ; III appears to be the exact opposite to this, being large in *O. ovatus* and *O. rugifrons* ; while IV is large in all species except *O. rugifrons*, in which it is small.

Keifer states that in the final instar there are usually seven or eight setae on the pedal lobes of the thorax. The first instar larvae appear to differ from this in that there are only five setae on each of the pedal lobes. Of these, four are large in *O. sulcatus* and *O. rugosostriatus*, three in *O. ovatus*, and only two large in *O. rugifrons*. The largest of these setae in each of the four species is slightly dilated at its extremity.

The number and size of the setae on the thoracic epipleura is another character studied by Keifer. In each of those first instar larvae examined by the writer there was only one small seta on the epipleuron, except in the case of *O. ovatus*, in which there were two very small ones. Snodgrass[11] considers this area would be better named the latero-tergite.

Abdomen.

The dorsa of the first seven abdominal segments differ from those of the thorax in being divided into four areas—namely, the prescutum, scutum, scutellum and the postscutellum. As on the thoracic prescutum, there is one seta on each side of the mid-dorsal line ; but the scutellum, on the other hand, usually bears five on each side with a pair on the lateral alar area. The eighth, ninth and tenth segments are often much modified from this pattern.

Seta I of all these segments is usually rather small, but in *O. ovatus* it is large, as on the thorax. The lengths of the setae then alternate, II being small, III large, IV small, and V large. On the eighth abdominal segment the position and size of seta II varies to some extent ; thus in *O. rugosostriatus* this seta is minute and anterior to the line of the other setae ; it is also minute in *O. sulcatus*, but not anterior. In *O. ovatus*, on the other hand, this seta is rather larger and anterior to the line, while in *O. rugifrons* it appears to be either vestigial or entirely missing. The identity of seta V on the eighth abdominal segment is rather obscure, since it may have been replaced by the large alar seta, or, alternatively, this latter seta may be the missing one.

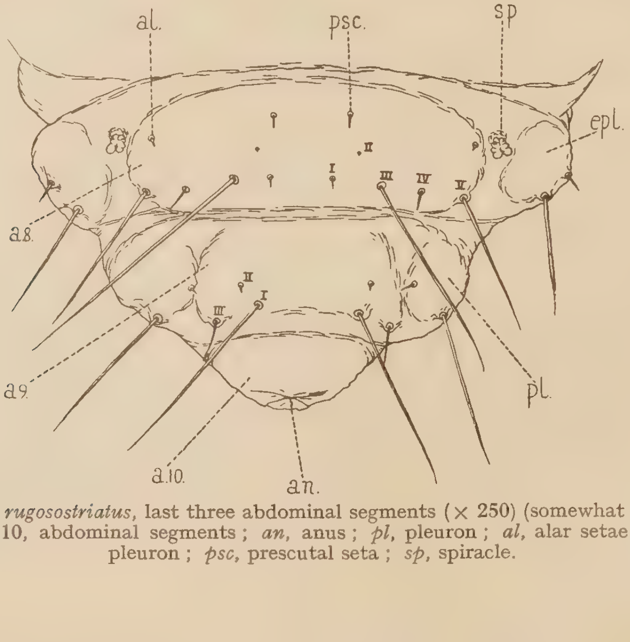

Fig. 3. *O. rugosostriatus*, last three abdominal segments (× 250) (somewhat flattened) : *a*.8, *a*.9, *a*.10, abdominal segments ; *an*, anus ; *pl*, pleuron ; *al*, alar setae ; *epl*, epipleuron ; *psc*, prescutal seta ; *sp*, spiracle.

On the ninth abdominal segment there are only three setae (I, II and III) on each side in the form of a triangle of which the apex is forward. Thus there are two large posterior setae and one small anterior one usually equidistant between them. In *O. rugifrons*, however, this anterior seta is minute and is directly in line anteriorly with the more medial of the two large setae.

In the first instar dissimilarities can also be found in the size of the smaller of the two setae on the hypopleuron of the eighth abdominal segment. In *O. sulcatus* this seta is very minute, while in *O. ovatus* it is definitely of medium size ; in the remaining two species its length lies between these two.

Another character observed by the present writer is the position of the spiracle in relation to the two alar setae and the larger one on the epipleuron. This is best seen on the second abdominal segment (fig. 4). In *O. rugosostriatus* the two alar setae, the spiracle and the epipleural seta are all in one line. This is also the case with *O. sulcatus*, except that the spiracle is some way anterior to the others. In *O. ovatus* and *O. rugifrons* the smaller alar seta, the spiracle and epipleural seta are in line, while the large alar seta is more posterior. There are, however, other differences between these two species in this region—for example, the seta *a.*I is much smaller in *O. ovatus* than in *O. rugifrons*, while in the former species seta V is much larger than *a.*II (not figured), and in the latter it is distinctly smaller.

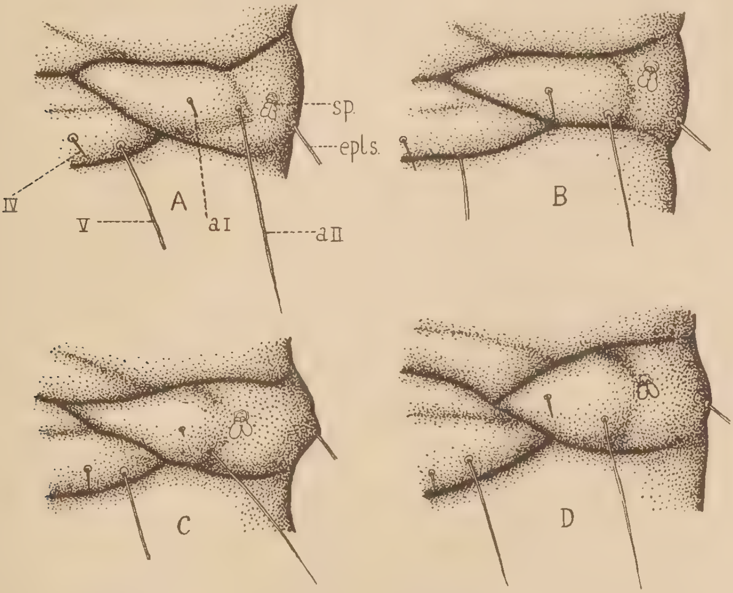

Fig. 4. Right side of 2nd abdominal segment, dorsal view, of A, *O. rugosostriatus* ; B, *O. sulcatus* ; C, *O. ovatus* ; D, *O. rugifrons* ; (× 275). *a.*I, *a.*II, alar setae ; IV, V, scutellary setae ; *epls*, epipleural setae ; *sp*, spiracle.

Spiracles.

A close study of the spiracles was not included in this work, since owing to their minute size they are not easy to examine and are, therefore, of little use for practical determination. It was noted, however, that they differ somewhat from those of the more mature larvae, having two rather large air-sacs, slightly prominent in form and showing annulations. The shape of the air-sacs is very variable even in a given specimen, but on the average those of *O. rugosostriatus* appear to have the lowest annulations nearer the base of the air-sacs which in this species are joined throughout their length. On the other hand, the bases seem to be rather more free in *O. ovatus*.

Setae of the Head, Thorax and Abdomen.

	Character	*O. sulcatus.*	*O. rugo-sostriatus*	*O. ovatus*	*O. rugifrons*
Head	Labrum, seta *a* ...	large separate	small medial	large medial	medium medial
	,, ,, *p* ...	small separate	large separate	small medial	large separate
	,, ,, *l* ...	small	medium	large	small
	Capsule, *sl* 2 ...	level	anterior	anterior	anterior
	,, *sm* 3 ...	in line	in line	posterior	posterior
	,, *sm* 1 ...	slightly posterior	behind *sl* 1	in line	in line
Thorax	Metascutoscutellum I	small	small	large	small
	,, II	large	large	small	small
	,, III	as I	as I	very large	large
	,, IV	large	large	large	small
	Epipleural	1 small	1 small	2 small	1 medium
	Pedal lobes	5 (4 large)	5 (3 large)	5 (4 large)	5 (2 large)
Abdomen	2nd abd, alar I ...	large	medium	small	medium
	,, II ...	posterior to spiracle	level	posterior	posterior
	Epipleural large ...	posterior to spiracle	level	level	posterior
	All segments seta I ...	small	small	large	small
	8th abdominal seta II	minute not ant.	minute anterior	small anterior	missing
	9th ,, ,,	small separate	small separate	small separate	minute medial
	8th hypopleuron small seta	minute	small	medium	small

Biology.

There appears in general to be a considerable similarity in the details of the life-history in each of the four species under consideration. Thus, for example, all of them are probably always parthenogenetic, the presence of males apparently never having been recorded.

The adult weevils usually emerge from the soil, where they have been pupating, about the end of April or in May, but Treherne[10] records that in British Columbia *O. ovatus* does not usually appear until the beginning of July. Egg-laying usually starts about seven to ten days after emergence. Hodson[6] records that each female *O. sulcatus* may lay up to 500 eggs in batches of five to twelve, while Smith[9] states that females of this species laid on an average 342 in a glasshouse, one female laying as many as 1,085, and 138 eggs outside. Treherne[10], on the other hand, states that *O. ovatus* lays on the average only 50 eggs. The single female of this species kept in captivity by the present writer laid even less than this number.

The position in which the eggs are laid varies somewhat with the conditions and the type of plant being infested. Most eggs are, however, placed in the soil near the surface. Many writers state that a few eggs may be placed on the petiole of the leaves if near the soil, or even on the crown in strawberries. The present writer noted the former habit with both *O. ovatus* and *O. rugosostriatus*, but not with *O. sulcatus.*

The eggs are whitish in colour when first laid, but after about one day they turn brownish, the young larvae usually hatching out in about 20 to 22 days. It has been recorded by some writers that the young larvae may feed on humus for the first few days, and Hardouin[5] considers that this may be an important factor in introducing the larvae of *O. rugosostriatus* into the roots of Cyclamen. Most of the species usually feed readily on the roots or leaves. Fox-Wilson[4] has noted the habit of the larvae of *O. rugifrons* of mining the leaves on which the eggs are laid, on such pot-plants as Saxifrage and Primula, for the first three to six days of their life ; after this period they migrate down the petiole to the roots. The habit of mining the leaves of Cyclamen where they touch the soil has also been observed in the other three species by the present writer.

The food-plants of these larvae are very varied, including such glasshouse plants as Cyclamen, Primula and Saxifrage, and outside strawberries, raspberries and, in the case of *O. sulcatus* and *O. ovatus,* forestry plants. Some writers consider that the race of *O. ovatus* attacking these latter plants is a distinct one, since the individuals will not feed on strawberries, nor will the strawberry race feed on forestry plants.

The larvae pass the winter in the soil, usually in an advanced state of development, but the date of pupation seems to be very variable. Thus Fox-Wilson[4] records specimens of *O. rugifrons* pupating as early as the middle of January and as late as mid-June. Most of the species, however, pupate about April or May, this stage lasting 17 to 23 days ; a specimen of *O. rugifrons* kept by Fox-Wilson seems on the other hand to have completed its pupal period in 12 days.

Pupation is carried out in an earthen cell, and after the adult weevil has emerged from the pupal skin, it remains in this cell for at least five to seven days, being in a soft and rather colourless state. If the weather conditions are not suitable it may remain in this position for some weeks. It appears that, in the case of *O. sulcatus* and *O. ovatus,* pupation may be postponed until the autumn, the species then over-wintering as adults. Downes[2] records that in *O. ovatus* hibernation takes place in houses, under piles of stones, or in warm climates even in the crowns of the strawberry plants. The present writer has, however, records of this species and also of *O. sulcatus* and *O. rugosostriatus* hibernating in the rubbish under hedges near the strawberries on which the weevils had been feeding during the summer.

These hibernating adults emerge earlier than those which pupate in the spring and commence laying eggs as early as March or April. The fertility of these eggs is, however, rather lower, being 68 per cent., as compared with 80 per cent. of those laid in the autumn. Whether those females that have oviposited in the previous autumn live to do so again in the spring appears at present to be unknown. The present writer has had in captivity for five months several females of *O. sulcatus* which laid freely in the preceding autumn and which are still living. Whether *O. rugosostriatus* and *O. rugifrons* have this habit of ovipositing after hibernation as adults has not been recorded.

Summary.

1. There are four species of *Otiorrhynchus* which commonly, in both the larval and the adult stage, cause damage to strawberry plants.

2. The morphology of the first larval instar of these species is discussed from the point of view of their determination.

3. It is shown that although the larvae in this stage are superficially very similar, there are considerable differences in the chaetotaxy of the head and also in the form of the labrum and the setae situated upon it.

4. Similarly there are variations in the position and size of the setae on the dorsum of both the thorax and abdomen.

5. A table is drawn up summarising all these characters in each of the four species.

6. A brief description of the present knowledge of the biology of these species is also given. It appears that although all of them are usually parthenogenetic, it is at present uncertain whether they can ever reproduce sexually, since the presence of males has as yet not been recorded.

7. These species usually have only one generation in the year, ovipositing in mid-summer and over-wintering as well developed larvae. In the case of *O. sulcatus* and *O. ovatus*, however, adults may emerge late in the summer and, having hibernated as adults, lay eggs in the early spring following.

References.

[1] Barrett, R. E. (1930). A study of the immature forms of some Curculionidae.—Univ. Calif. Publ. Ent., **5,** no. 5, pp. 89–104.

[2] Downes, W. (1920). The strawberry root weevil in British Columbia.—50th Ann. Rep. Ent. Soc. Ontario, 1919, p. 84.

[3] Feytaud, J. (1918). Etude sur l'Otiorhynque sillonné (*O. sulcatus*).—Ann. Epiphyt., **5,** pp. 145–192.

[4] Fox-Wilson, G. (1925). The mining habits of *O. rugifrons* larva.—Ent. Mon. Mag., **61,** p. 273.

[5] Hardouin, R. (1931). Matériaux d'éthologie concernant *O. rugosostriatus*.—Bull. Soc. ent. Fr., 1931, pp. 179–182.

[6] Hodson & Baumont. (1931). On the biology and control of *O. sulcatus*.—Pamph. Seale Hayne Agric. Coll., no. 36.

[7] Keifer, H. H. (1932). Some Pacific Coast Otiorhynchid weevil larvae.—Ent. Amer., **13.**

[8] Rymer Roberts, A. W. (1926). On the early stages of some weevils (Curculionidae).—Ann. Appl. Biol., **13,** p. 197.

[9] Smith, F. F. (1927). The black vine weevil (*O. sulcatus*) as a pest of greenhouses and nurseries.—J. Econ. Ent., **20,** p. 127.

[10] Treherne, R. C. (1914). The strawberry root weevil in British Columbia.—Canad. Dep. Agric. Ent. Bull., no. 8.

[11] Snodgrass, R. E. (1935). The Principles of Insect Morphology.—New York & London, pp. 72, 250.

SOME RESULTS OF A STUDY OF INSECTS BY MEANS OF LIGHT TRAPS IN CENTRAL ASIA.

By P. P. Bogush.

Work was carried out by the Turkoman Branch Plant Protection Station of the Cotton Scientific Research Institute in Central Asia between 1930 and 1934 on the use of light traps, particularly for the study of the cotton pests *Laphygma exigua* and *Earias* spp. The information obtained, however, throws considerable light on many other problems and a brief outline of some of these is presented below.

One trap (fig. 1), with a 500-watt light, was in use at Bairam-Ali, Turkmenistan, from spring to autumn in 1930-1934, and in 1932 eight traps were in operation along the southern border of Central Asia. Under Central Asiatic conditions insects are greatly attracted by light, the catch at Bairam-Ali reaching 150,000 individuals in a single night. Among the groups attracted are Blattoidea, Mantoidea, Orthoptera (in particular the Acrididae), Dermaptera, Homoptera, Hemiptera, Coleoptera (as many as 20,000–30,000 Elateridae in a single night), Neuroptera, Diptera, Hymenoptera and Lepidoptera.

(1) The trap is of great value in detecting the presence of insects when only present in small numbers. For example, at Bairam-Ali, in 1932, the trap showed *Laphygma exigua* to be present from spring to autumn, although by other methods only a few individuals were seen. In 1930, the first year of the trap installation, both *Loxostege sticticalis* and *Pyrausta nubilalis* were detected for the first time at Bairam-Ali, although the Entomological Organisation had been in existence for more than ten years. The same may be said about *Gryllotalpa africana*, which was detected for the first time in Central Asia by means of the trap.

(2) The trap method is of use in recording the immigration of insects from surrounding country. Thus in May 1933 there was such a flight of *L. exigua*, evidently from the adjacent waste lands.

(3) The material collected can be examined for the state of sexual development. Thus in the above flight of *L. exigua* it was found that many moths had empty ovaries and therefore oviposition was insignificant.

(4) By means of the trap help may be obtained in problems of bio-ecology. Thus, in 1932, in studying the species of *Earias*, two species, *E. turana* and *E*. sp. nov., were first found in the trap. Later it was discovered that they were associated with *Salix* sp., among which they should have been searched for.

(5) The trap plays an important rôle in securing a rapid knowledge of the fauna of unknown districts. It often gives better results than most other methods, especially in estimating the whole insect complex. Thus in 1932 the southern limit of quite a large number of species of insects was determined. Over fifty species of insects of different genera and families were observed, including *Gryllus burdigalensis, Gryllotalpa unispina, Calliptamus siculus, Adelphocoris lineolatus, Agriotes meticulosus, Plutella maculipennis, Celerio livornica* and *Heliothis obsoleta*.

(6) Traps are of considerable use in phenological problems. Frequently the day to day curves of captures show definite maxima for the different generations, and so the duration and time of maximum abundance of each brood can be obtained. Thus *Loxostege sticticalis* in Turkmenistan must have not less than four generations. Three summer generations of this species complete their development in about 40 days each. *Agrotis segetum* has up to four generations and development takes about

55 days. *Feltia exclamationis* has only two generations, the first of which takes 85–90 days.

(7) The trap catches can be compared with the number of insects in the field and from this, after a time, it may be possible to estimate or foretell the field infestation from the light trap figures. Thus fig. 2 shows data on the flights of *L. exigua*, from which the danger periods in the second and third generations can be estimated as shown in the lower half of the diagram.

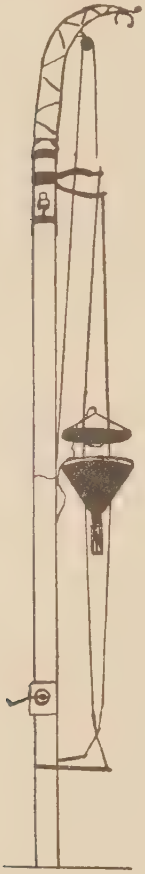

Fig. 1. The light trap.

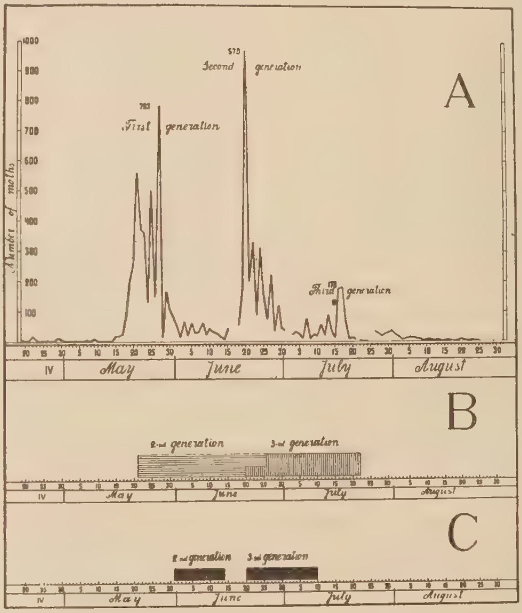

Fig. 2. Graph showing the periods of damage caused by *Laphygma exigua* and its control in Bairam Ali, 1930. A, number of moths caught by the light trap; B, theoretically estimated periods of damage by 2nd and 3rd generations; C, periods of actually accomplished control.

In the case of *Agrotis segetum* in Bairam-Ali in 1931, the April generation consisted of only five individuals on five nights. In 1934 the flight increased to seventeen individuals. As a result of this the forecasting of a more serious attack was made two months ahead of its arrival. The small number of moths attracted by the light can be explained by the slight positive phototropic response of *A. segetum*, which renders the forecastings rather uncertain in the case of this species, though they were fully justified by the observations carried out in different years.

(8) If the successive generations can be separated on the trap records, as has been done by the author in the case of *Laphygma exigua* (fig. 3), and if the oviposition rate is known, it is possible to obtain information about the survival of the different generations. This can be obtained by means of a comparison of the actual flight with that estimated theoretically. Thus in 1930 the survival of the second generation of *L. exigua* was 0·14 per cent., and of the third 0·07 per cent. For the maintenance of the species under Central Asiatic conditions a high oviposition rate is necessary, namely, up to 2,000 eggs per female, as compared with 500 eggs under Astrakhan conditions. Even a slight increase in the percentage survival can cause an outbreak to occur.

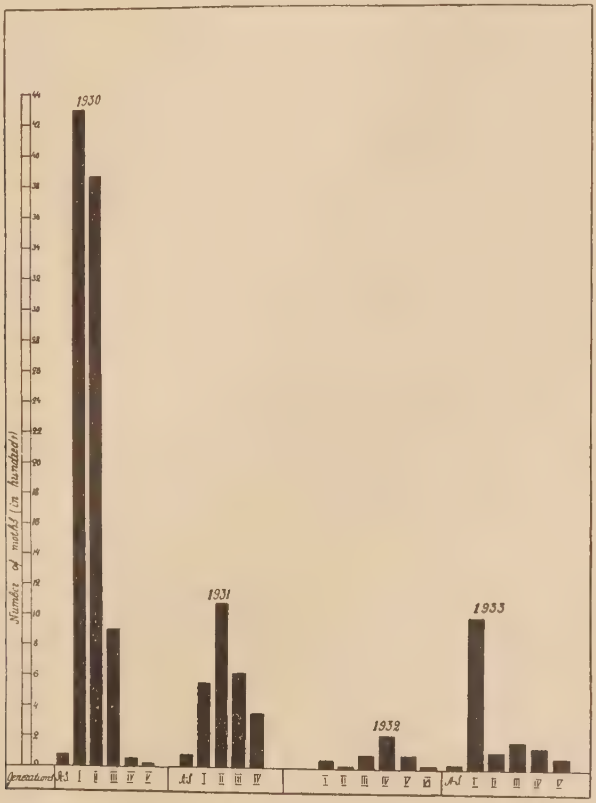

Fig. 3. The number of *Laphygma exigua* at Bairam-Ali, 1930–1933, according to the data obtained from light traps. Generations : a–s (autumn-spring) and I–VI.

(9) If data are taken over a series of years it is possible to show a relation between the size of the brood and climatic conditions. Thus fig. 4 shows the relation between the mean temperature at Bairam-Ali in December, the attraction of *Laphygma* of the first generation by light at the same place in the spring of the following year, and also the area treated (which was under control) against this pest over the whole of Turkmenistan.

It will be seen that there is a distinct positive correlation between the numbers attracted by light and the areas treated (coefficient of correlation being +0·9), and a negative correlation between these two and the mean temperature in December (coefficients of correlation —0·8 and —0·7 respectively).

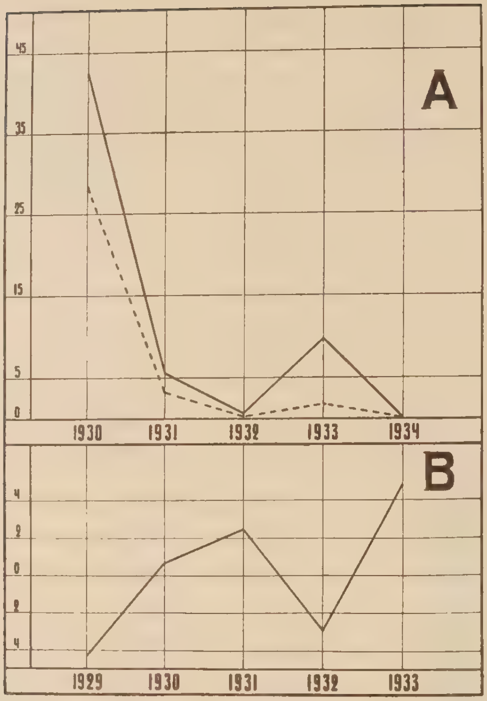

Fig. 4. The relation between the mean temperature during December, the attraction of *L. exigua* by light, and the size of the areas treated. A (straight line), the number of moths of the 1st generation (in hundreds) collected by the light trap at Bairam-Ali, 1930–1934; (broken line), the size of treated areas over the whole Turkmenistan Republic, 1930–1934 (in thousands of hectares). B, mean temperature during December at Bairam-Ali, 1929–1933 (C°).

In the case of *Agrotis segetum*, in spite of its slight attraction by light, a very close positive correlation between the number of moths flying in the spring and the extent of the treated area is observed (correlation coefficient being +0·9). There is also a positive correlation between these two and the mean temperature in December (for both cases the correlation coefficients being +0·9). The high correlation makes it possible to forecast the character of the outbreaks of *L. exigua* and *A. segetum* approximately five months previous to their occurrence.

Of course, the data received during so short a period (4–5 years) cannot be considered reliable enough. Therefore it is necessary to carry out work along this line for some years more.

(10) Up to now the light traps have not been tested as a means of insect pest control. However we have observed that many injurious insects, both females and males, were attracted by light, the females having the ovaries in every stage of development. This gives reason to expect that the light trap might be successful as a means of control against some species, in particular against the Cerambycid, *Aeolesthes sarta*, which attacks trees. The question of the relative number of injurious, useful and neutral insects trapped has not, however, been sufficiently studied.

Such an extensive use of light traps for plant protection is explained by the specific conditions of Central Asia. The high temperature and light winds, as well as the relative stability of the weather during the vegetation period prevailing in Central Asia, are of great importance.

OBSERVATIONS ON THE PUPAL RESPIRATION OF SOME INSECTS OF ECONOMIC IMPORTANCE.

By F. A. Squire,

Supernumerary Entomologist, Department of Agriculture, British Guiana.

The question of pupal respiration is one not only of scientific interest, but also of some economic importance inasmuch as it concerns the welfare of pupae of beneficial insects in transit from one country to another. It is possible that a more exact knowledge of the oxygen required by pupae and the carbon dioxide given off may lead to more suitable packing arrangements and thus to a higher percentage of recovery at the receiving end. It is well known that larvae and adults even when not particularly active respire far more vigorously than pupae, yet it will be seen from the figures given below that pupae do breathe quite appreciably, especially at the beginning and at the end of the instar, and that their oxygen requirement is by no means negligible, above all under tropical conditions.

The term respiration as applied to the exchange of gases that takes place during pupal development is no doubt questionable, as there are no respiratory organs during the greater part of the instar, but it can easily be shown by simple experiments that oxygen is absorbed from the atmosphere, and the present experiments prove that CO_2 is given off, so that the process is fundamentally respiratory in spite of the absence of the usual organs.

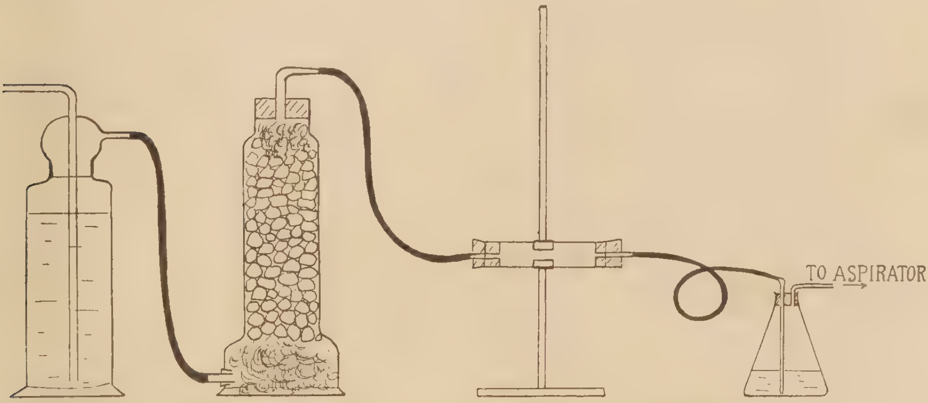

Fig. 1. Apparatus used to measure pupal respiration.

It was with these considerations in mind that the following investigation was made in the Entomological Laboratory of the Department of Agriculture in British Guiana. Owing to the even temperature prevailing here, it was possible to carry out the experiments at a constant temperature of 80°–83°F. Even within this narrow limit an increase in temperature results in increased respiration, but not so markedly as to obscure the general trend of the curves. The air used, as will be seen from the description of the apparatus, was dry.

Description of Apparatus.

The apparatus used (fig. 1) consisted of a Drechsel bottle of potassium hydroxide solution to absorb atmospheric carbon dioxide and at the same time to enable the rate of flow of air to be roughly gauged ; a lime soda tower for absorbing the remaining traces of carbon dioxide and to dry the air ; a 4-in. combustion tube in which the pupae were placed ; a wash-bottle with 5 cc. of $\frac{N}{100}$ potassium hydroxide solution (measured with a micro-pipette) diluted with distilled water and coloured with phenolphthalein, and an aspirator. The apparatus was connected up by means of rubber stoppers and tubing. The pupae were placed in the tube for an hour on each day of the pupal period, and the air was drawn through the apparatus at a uniform rate. At the end of the hour the flask was removed and the contents neutralised by titration of 5 cc. of $\frac{N}{100}$ sulphuric acid with a micro-burette and the weight of carbon dioxide given off calculated.

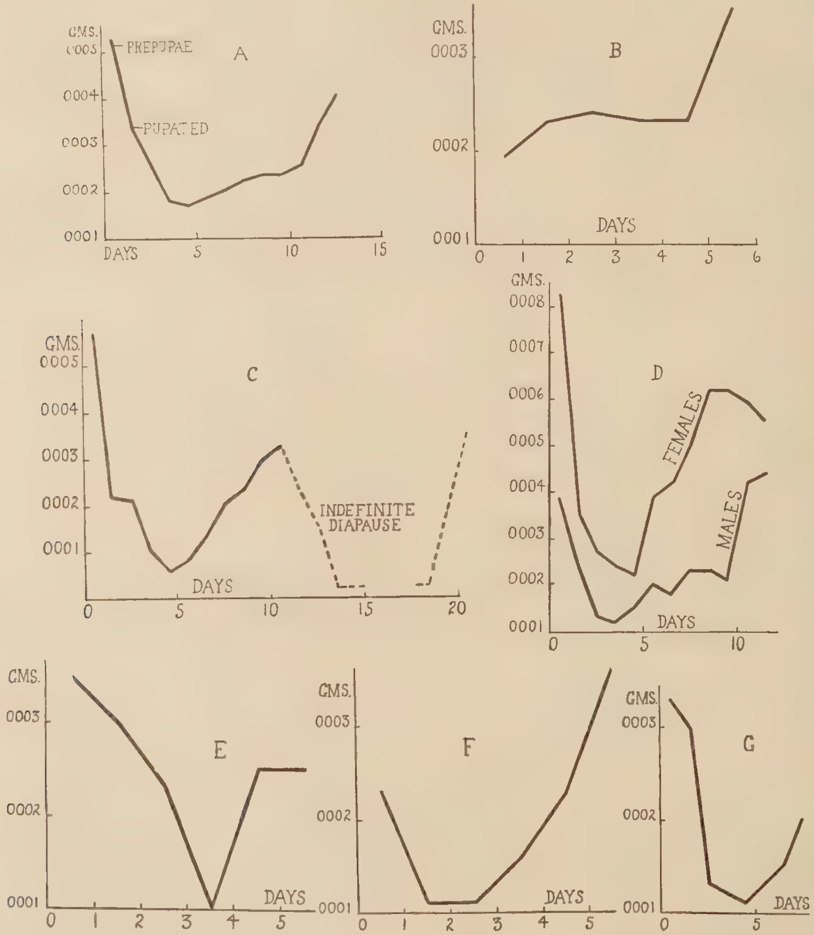

Fig. 2. The graphs represent the amount of CO_2 given off during one hour on successive days of the pupal period. A, *Pyrrhopyge amyclas*, Cram., 5 pupae ; B, *Hydrous smaragdinus*, Brullé, 2 pupae, total weight 3·79 gm. ; C, *Papilio anchisiades*, Esp., 4 pupae, total weight 4·53 gm. ; D, *Brassolis sophorae*, L., 3 female pupae, total weight 6·46 gm., 6 male pupae, total weight 6·02 gm. ; E, *Utetheisa ornatrix*, L., 8 pupae, total weight 1·79 gm. ; F, *Diatraea saccharalis*, L., 11 pupae, total weight 0·98 gm. ; G, *Metagonistylum minense*, Towns, 28 puparia.

The Results Obtained.

The results obtained are illustrated by graphs, which it will be seen are nearly always of approximately parabolic form—the highest values being at the beginning and at the end of the pupal period and the lowest in the middle. In other words there is a gradual decline in the rate of respiration during the first half of the instar, followed by a similar increase during the latter half. Actually the rate of respiration is highest at the beginning of the prepupal stage, as is evident from the curve given by *Pyrrhopyge amyclas*, the guava fire-tail moth. The graphs represent the amount of CO_2 given off during one hour on each successive day of the pupal period. Readings were taken as nearly as possible at the same time every day, so as to create regular intervals of 24 hours between observations.

The case of the water beetle, *Hydrous smaragdinus*, is somewhat different. Here there is a continuous rise in the respiratory rate throughout the six days of the pupal period. This difference is perhaps best accounted for by the fact that there is an unusually long prepupal period of five days, during which most of the histolytic and histogenetic changes take place, since at the time of pupation all the imaginal parts and members are already quite evident. The same respiratory curve is doubtless characteristic of many other exarate pupae. In the case of the obtect and coarctate pupae experimented with there was but a short prepupal stage, so that the katalytic activities commenced at the time of or only shortly before pupation.

Respiration during Diapause.

The case of the " orange dog," *Papilio anchisiades*, is interesting in that there is invariably a marked pupal diapause in some of the individuals of each brood. There is no means of distinguishing between those that will emerge on time and the rest, but in some of the experiments with this species it happened fortunately that all pupae selected for the experiment remained in diapause for longer or shorter periods, so that continuous readings uncomplicated by timely emergences were obtained. Here it will be seen that there is a typical obtect pupa respiration curve, *i.e.* a steady decline for the first half of the instar followed by a rise. On the last day of the normal pupal period, however, the rate of respiration drops almost to zero, where it remains for the whole of the diapause, which may be anything from 2 to 100 days. At the end of the diapause there is a marked increase in respiration, which is accompanied by visible changes. The pupa grows dark brown, then black, and becomes soft to the touch, and within 24 hours of the onset of these symptoms emergence takes place. Pupae dissected during the diapause showed that the larval organs had all disappeared. The cavity was filled with yellow fat-body, and, with the exception of the first indication of the antennae and mouth-parts, none of the imaginal organs were yet constituted.

Loss in Weight during the Pupal Period.

In the case of every species experimented with, it was found that the weight decreases by approximately the same amount each day. Thus three female pupae of *Brassolis sophorae*, L., were weighed together on each of the thirteen days of the pupal period and the following reading obtained :—

Weight	*Differences*
6·46 gm.	
6·38 ,,	·08 gm.
6·29 ,,	·09 ,,
6·22 ,,	·07 ,,
6·14 ,,	·08 ,,
6·09 ,,	·05 ,,

Weight	*Differences*
6·01 gm.	·08 gm.
5·91 ,,	·10 ,,
5·78 ,,	·13 ,,
5·70 ,,	·08 ,,
5·61 ,,	·09 ,,
5·53 ,,	·08 ,,
5·45 ,,	·08 ,,

Similar results were obtained for male pupae of *Brassolis sophorae*, as well as for other species, such as the tiger moth, *Utetheisa ornatrix*, L. ; the small moth-borer of sugar-cane, *Diatraea saccharalis*, L. ; the Amazon fly, *Metagonistylum minense*, Towns. ; and the "orange dog," *Papilio anchisiades*, Esp. It was thought that this loss in weight might prove to be in quantitative agreement with the weight of CO_2 given off, but it appears rather to be due to loss of moisture. It is not however, as one might suppose, the result of being kept for an hour each day in dry air, as pupae other than those experimented with gave similar results.

Conclusions.

In conclusion it may be said that the periods of greatest physiological activity as indicated by the rate of respiration occur at the beginning and at the end of the prepupal-pupal instar. Evidence obtained from dissections supports this. In the case of *Brassolis sophorae* pupae of all ages were dissected. In pupae one day old practically all the larval organs had disappeared. This bears witness to the great histolytical activity during the short prepupal period of 1–2 days. The pupal content is a soup consisting of fatty globules and shreds of tissue. The latter gradually disappear during the 2nd, 3rd, and 4th days ; on the 7th and 8th days the eggs can be plainly distinguished in the case of the female ; on the 9th day the appendages are formed ; during the 10th and 11th days the internal imaginal organs are completed ; and on the 12th day emergence takes place.

Thus it appears that the most marked changes occur during the prepupa and the 1st to the 3rd days of the pupal instar, and again on the 9th to the 12th days.

In the case of *Hydrous* the actual pupal period represents the tail end of the physiological changes leading to the constitution of the imago, most of them having already taken place in the prepupal stage.

Acknowledgments.

I have great pleasure in acknowledging with thanks assistance received in the course of this investigation from the Chemical Division of the Department of Agriculture and from Mr. W. R. Clark, of Queen's College, Georgetown, British Guiana.

ON TWO BRACONIDS (HYM.) BRED FROM ECONOMIC HOSTS.

By D. S. Wilkinson,

Imperial Institute of Entomology.

Mirax leucopterae, sp.n.

♀♂. Black ; head (including palpi), all legs (including the coxae, but excluding the feet which are strongly darkened), tegulae, and certain portions of the basal joint of the scape, pale red testaceous ; the lateral membranous portions of the 1st and 2nd tergites, and the basal ventrites, very pale red testaceous ; the plate of the 1st tergite only weakly coloured, and of the 2nd not much more strongly so, both probably more rightly describable as pale red testaceous also ; 3rd tergite (except laterally and right across apex) also weakly coloured ; the flagellum, and certain portions of the scape, brown ; wing-veins and stigma brown, and the setae of the wings coloured ; apical third of stigma commonly appearing to be to some extent hyaline.

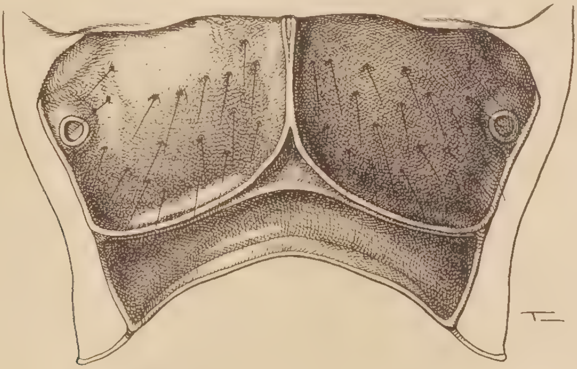

Fig. 1. *Mirax leucopterae*, sp. n., propodeon (× 165).

♀♂. *Head* exceedingly minutely punctate, more densely so on the face than on the frons and vertex ; ocelli in a small equilateral triangle which is about as long as its distance from each eye ; flagellum of ♀ rather shorter, and of ♂ rather longer, than the combined length of head, thorax, and abdomen. *Thorax* : mesonotum and disc of scutellum throughout regularly, minutely punctate (degree 1) ; notauli very distinct on the short anterior perpendicular face of the mesonotum, otherwise entirely wanting ; scutellar sulcus wanting ; propodeon (fig. 1) with a very strong median longitudinal carina, which bifurcates at about the middle and forms a pair of very strong, diverging carinae, these latter reaching and joining with the lateral longitudinal delimitating carinae, which also are very strong ; the diverging carinae often appear to be doubled by a carina that runs close alongside them posteriorly to them, but which does not run up into the angle of the bifurcation, but forms, consequently, a small triangle ; this transverse carina often absent or obsolete ; propodeon otherwise without sculpture, save that in the two basal areas it is punctate (degree 2) and setiferous ; apically the propodeon strongly emarginate ; mesopleurae entirely smooth and highly polished. *Wings* (fig. 2) : the punctiform 1st abscissa of the radial vein emitted before the middle of the stigma. *Abdomen* : 1st tergite with its plate long and narrow, but broadened somewhat in apical half ; 2nd tergite entirely smooth save for two or three minute punctures, its membranous lateral-basal areas with fine longitudinal aciculation; 3rd tergite with some minute punctures across apical third or fourth, otherwise almost throughout (namely in the semi-membranous area) with fine longitudinal aciculation.

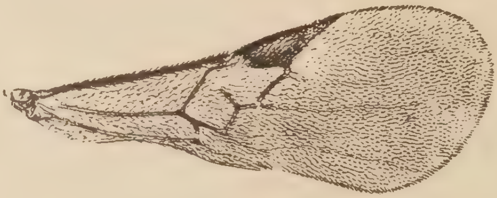

Fig. 2. *Mirax leucopterae*, sp. n., forewing. (×35).

Length, 1·5–2·0 mm.

TANGANYIKA TERRITORY: Bukoba, Nyakato, 5 ♀♀ (one the *type*), 4 ♂♂, 24.viii. 1935; Moshi, 2 ♀♀, 1 ♂, 17.xi.1934, 1 ♀, 1 ♂, 31.xii.1934 (*A. H. Ritchie*).

Type deposited in the British Museum.

Host.—The 1935 series is labelled as having been bred from the Tineid *Leucoptera daricella*, Meyr., on *Pavetta ternifolia*; and the 1934 series from *Leucoptera* sp. from *Cremaspora africana*.

Commentary.—This interesting new species may readily be separated from the only other as yet described from Africa, namely *Mirax africana*, Brues 1926, by means of the sculpture of the propodeon. The propodeon in *africana* is described as " with distinct median and a lateral longitudinal carina; more or less irregularly reticulate between the carinae, more coarsely so behind." The strong, well marked carination on the propodeon in *leucopterae* is sufficient also to separate this species from the two European species, *Mirax spartii*, Hal., which is well represented in the collections in the British Museum, and *M. dryochares*, Marsh., which is unknown to me.

It is perhaps of interest also to note that Bainbridge Fletcher (1920) states that *daricella* was " originally described from Queensland, and since recorded from S. Africa, Ceylon, Burma, and India." The closely related species, *Leucoptera coffeella*, Guér., also occurs in Tanganyika Territory, and doubtless is also parasitised by *Mirax leucopterae*. This latter moth is recorded by Walsingham from Central and South America and the West Indies, while Box (1923) in addition has collected together records of its occurrence in Ceylon, Madagascar, Mauritius, Réunion, and Arabia, and in Uganda and Kenya Colony.

Since *L. coffeella* occurs in America, although apparently introduced, it was obviously necessary also to consider the species of *Mirax* described from that continent. Five species of *Mirax* have been described by Ashmead from America, namely *aspidiscae*, *minuta*, *lithocolletidis*, *grapholithae*, and *pallida*, and three species more recently by other authors, namely *ectoedemiae* Rohw. (originally under the generic name *Centistidea*, which was erected for the reception of this species, and which was sunk by Muesebeck under *Mirax*), *brasiliensis*, Brues, and *texana*, Mues. All these eight species are unknown to me, but none of the descriptions can possibly be made to agree with this species I have here described as new.

Fornicia chalcoscelidis, sp. n.

♀. Black; mandibles (except at base), the four anterior femora and tibiae, the tibial spurs of the front legs, the front tarsi (except for darkened feet), middle tarsi (except for darkened feet and apical joint), hind femora (except for some black at extreme apex), about apical two-fifths of hind tibiae, and the basal joint of the hind tarsus at extreme base, red testaceous ; about basal two-fifths of hind tibiae white, the remainder of the hind tibiae black, except where stated above to be red testaceous ; palpi (except for darkened basal joint), and the tibial spurs of the four posterior legs, white ; tegulae testaceous and transparent in about the apical half, black and opaque basally ; wing-veins at extreme base of wing pale, the wing-veins otherwise, and the stigma and metacarp, brown ; wings hyaline, the setae coloured.*

♂. Agrees perfectly with the above description of the ♀, save as follows :—Wing-veins throughout pale to colourless ; stigma and metacarp brown, the stigma with some indication of a basal cloud ; wings white hyaline, the setae white.*

♀♂. *Head* : face punctate ; clypeus largely impunctate ; vertex and occiput with minute and widely separated punctation ; flagellum of ♀ rather shorter than, and of ♂ distinctly longer than, combined length of head, thorax, and abdomen. *Thorax* : mesonotum with a clean, fine, well marked, median longitudinal carina, which is about as high as it is broad, and narrowly alongside of which in about its anterior three-fifths the integument is slightly sunken and reticulate ; the lines of the notauli indicated by broad, more or less reticulate, or strongly punctate, bands, which converge posteriorly and run into a large area, which area occupies the majority of the posterior two-fifths of the mesonotum, and which is covered throughout with strong, closely placed, clean (not rugose) punctation ; narowly round the lateral margins, and broadly across the front margin, the mesonotum is grossly sculptured ; otherwise the mesonotum is coriaceous, with some secondary punctation anteriorly only and not throughout the coriaceous areas as in *F. ceylonica*, but at apex broadly across in front of the strongly crenulate scutellar sulcus the mesonotum is entirely smooth and highly polished ; scutellum triangular, convex, with some coarse sculpture and punctation, shortly produced apically into a single, obliquely raised, truncated prominence, which in profile is very thin ; metanotum medianly with a short spinelike process ; propodeon much as in *F. ceylonica*. *Wings* very like those of *F. ceylonica*, but with the metacarp relatively shorter. *Legs* : hind coxae on outer faces throughout with strong, closely placed, clean (not rugose) punctation, much as in *F. africana*, this punctation in the ♂ weaker and more sparsely placed than in the ♀ ; the longer hind tibial spur of the ♀ rather longer than three-fifths, of ♂ rather less than half, and the shorter spur of the ♀ half, of the ♂ about three-eighths, the length of the basal joint of the hind tarsus. *Abdomen* : very like that of *F. ceylonica* except that the raised median longitudinal area definitely extends to apex of 3rd tergite, as in *F. africana*.

Length : ♀, 4·5 mm. ; ♂, 3·5 mm.

MALAYA : Prov. Wellesley, 1 ♀, 3 ♂♂, 7.ii.1936, 3.iii.1936 (*G. H. Corbett*).

Type deposited in the British Museum.

Host.—The Limacodid, *Chalcoscelis albiguttatus*, Snell.

On account of its unidentate scutellum, this new species runs to couplet 4 of Cushman's key (Phil. Journ. Sci., 40 : 234–235), but of the species therein referred to it will agree neither with *borneanus*, Cush., nor *moronis*, Cush., on account of differences in the sculpture of the mesonotum and in the colour of the legs, nor with *annulipes*, Ashm., on account of the colour of the legs, according to Cushman's descriptions. As to my own species that have the scutellum unidentate, *chalcoscelidis* is quite obviously distinct from *africana*, large areas of whose mesonotum are strongly reticulate ; and from *ceylonica*, whose mesonotum is much smoother, it is immediately separable by means of the relative lengths of the metacarp, in addition of course, in both cases, to other characters. The metacarp in *ceylonica* is longer than the stigma and considerably longer than the distal portion of the upper margin of the radial cell ; and in *chalcoscelidis* it is about equal to or even rather shorter than the length of the stigma, and about equal to the length of the distal portion of the upper margin of the radial cell.

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* These differences between the sexes as regards the colouring of the wings are thus describable for *Fornicia ceylonica* also.

A list of the species now referable to *Fornicia*, showing to which section of the genus each species belongs, is perhaps not out of place at this juncture, particularly since, to my regret, I am not in a position as yet to write a comprehensive key.

Species with unidentate scutellum.

1. *F. annulipes*, Ashmead, 1905, Can. Ent., **37** : 7. Manila.
2. *F. arata*, Enderlein, 1912, Ent. Mitt., **1** : 261. Formosa.
3. *F. ceylonica*, Wilkinson, 1928, Bull. Ent. Res., **19** : 262. Ceylon.
4. *F. borneanus*, Cushman, 1929, Phil. J. Sci., **40** : 236. Borneo.
5. *F. moronis*, Cushman, 1929, Phil. J. Sci., **40** : 237. Philippine Is.
6. *F. africana*, Wilkinson, 1930, Bull. Ent. Res., **21** : 275. S. Rhodesia.
7. *F. chalcoscelidis*, Wilkinson, 1936, Bull. Ent. Res., **27** : 386. Malaya.

Species with bidentate scutellum.

8. *F. clathrata*, Brullé, 1846, Hist. nat. Ins. Hym., **4** : 512. Brazil.
9. *F. arata*, Enderlein, Cushman, 1929, Phil. J. Sci., **40** : 235.* Formosa ; China.
10. *F. penang*, Cushman, 1929, Phil. J. Sci., **40** : 235. Penang I.
11. *F. tagalog*, Cushman, 1929, Phil. J. Sci., **40** : 236. Philippine Is.
12. *F. thoseae*, Wilkinson, 1931, Bull. Ent. Res., **21** : 485. Celebes.

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* Cushman assigns the name *arata*, End., to material that he himself describes as having the scutellum bidentate, despite the fact that Enderlein erected for his new species *arata* the new genus *Odontofornica* chiefly because the scutellum was *not* bidentate.

BERLESE'S FLUID: REMARKS UPON ITS PREPARATION AND USE AS A MOUNTING MEDIUM.

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Introduction.

Berlese's fluid has been known to entomologists for many years as a medium for making microscope mounts of small Arthropods; it has not been widely used, for which its unreliable keeping quality is perhaps partly responsible. It was developed by the late Professor A. Berlese, chiefly as a mountant for mites; apparently he did not publish the formula. Dr. J. Davidson, now Head of the Department of Entomology at the Waite Institute, informs me that when he was working in Berlese's laboratory in Florence in 1919, Berlese gave him the formula; Dr. Davidson used it at Rothamsted with splendid results for making slide preparations of aphides. The formula was published in 1921 by Bolles Lee from details supplied by Dr. A. D. Imms and was repeated in later editions (1924, 1928). Imms (1929) and Eltringham (1930) also refer to it; the former gave it the appropriate name " Berlese's Fluid." Gater (1928) made slight modifications in the formula, including the addition of cocaine.

When the medium is made up according to the published formula, recrystallisation may take place in it after it has stood for some time; this may also occur under the coverslips of mounts, making them opaque. The writer has modified the formula with the object of correcting this defect; it appears that the amount of chloral hydrate stated is excessive. A modified formula containing less chloral hydrate has been used by the writer for over two years with satisfactory results. The following details of the preparation and use of the mountant may be of interest to zoologists.

Formula.

The following formula is that given by Bolles Lee and by Imms (*loc. cit.*) :—

Distilled water	20 mils.
Chloral hydrate	160 grams.
Gum arabic	15 grams.
Glucose syrup	10 grams.
Glacial acetic acid	5 mils.

In making up the formula a large excess of chloral hydrate remains undissolved at room temperature. The mountant is really the filtered, supernatant fluid, being a saturated solution of chloral hydrate. With loss of water by evaporation, aided by falling temperature, recrystallisation often occurs; the stock solution may become largely crystalline and slide mounts opaque. The latter effect results from the formation of a felting of delicate, needle-shaped crystals* which completely or partly obscure the mounted object; this difficulty has been encountered by several workers. The fault may be corrected by running glacial acetic acid round the coverslip, and then warming the slide until slight ebullition of the mountant takes place.

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* I have been unable to obtain any information regarding the chemistry of possible reactions in the mixture other than recrystallisation of chloral hydrate; I have therefore presumed that this takes place.

The amounts of chloral hydrate dissolved by 20 mils. of water at particular temperatures are as follows (Seidell, 1928) :—

Temperature (°C.)	*Weight of Chloral hydrate*
10	75 grams
15	99 ,,
20	132 ,,

The only other solvent in the formula is acetic acid ; no data appear to have been published as to the solubility of chloral hydrate in this substance. A rough test indicates that 5 mils. would dissolve about 10 grams at ordinary temperatures. To avoid saturation of the medium with respect to chloral hydrate, the lowest (winter) laboratory temperatures must be considered ; in Adelaide about 10°C. is the average for the coldest part of the year. It was therefore decided to use 60 grams instead of 160 grams of chloral hydrate ; this amount readily dissolved without residue, and no sign of deterioration has appeared in the stock solution after more than two years.

Preparation.

The ingredients do not require any special order of mixing. It may be noted that glucose syrup is usually obtained ready made up ; otherwise it may be prepared according to the British Pharmacopoeia standard.

Filtration of the medium is necessary ; a filter pump and Buchner funnel are desirable. Glass-wool or good quality cotton-wool may be used for filtering ; after placing in the funnel, the material should first be washed through with distilled water to remove loose fibres.

Properties.

The resulting mountant is a glassy to pale amber liquid (depending on the colour of the gum arabic) of low viscosity. It does not undergo any change of colour with time. Its refractive index has been determined as 1·461 (for the modified formula). The following values (taken from Imms, 1929) may be compared :—

Canada Balsam	1·524
Euparal	1·483

The low refractive index of Berlese's fluid permits of extremely clear microscope images of transparent objects. Imms (*loc. cit.*) has referred to other useful properties of the medium ; in particular the presence of acetic acid results in the fixation of lightly chitinised objects in an extended condition.

The keeping quality of mounts appears to be very satisfactory ; and the mounts for most purposes are permanent. I have seen slides about ten years old which, except for cases of crystallization, show no signs of deterioration. Finally it may be noted that the acid nature of the medium renders it unsuitable for mounting stained objects ; where it is used, however, staining is seldom required.

Mounting Technique.

Certain points in connection with mounting technique seem worthy of further mention. General directions are given by Imms (1929). Small insects or Acarina may be placed alive into a drop of the mountant on a slide, a coverslip dropped on and the slide warmed over a low flame or hot-plate. This gives a mount in which the appendages of the object mounted are usually well extended and symmetrically arranged. Heavily chitinised objects may be treated first with potassium hydroxide, and, if necessary, bleaching agents. In such cases, it is necessary to pass through 10 per cent. acetic acid to the mountant. This treatment with acetic acid is optional with live material, but essential with preserved material. The warming of the slide is an important step ; it results in extending the object and expelling air, and also in sealing the edge of the coverslip. Such a mount under Australian conditions is permanent without ringing. Clearing of the object occurs in a day or so without the use of special agents ; generally a mount may be examined immediately.

A large round coverslip is desirable ; where the object is large, a hollow ground slide is necessary, in order to permit sealing. Where large chitinised objects are to be mounted, a mountant such as euparal is more suitable than Berlese's fluid.

The following groups, in the experience of the writer, may with advantage be mounted in Berlese's fluid : all Apterygota and APHIDIDAE, most COCCIDAE, Anoplura, and Thysanoptera (these give excellent mounts from fresh material) ; Psocoptera, certain Diptera and Hymenoptera mount well in it. It is excellent for most small insect larvae. Gater (1928) has discussed its use in the examination of mosquito larvae.

For Acarina it has proved an indispensable mountant. The writer has also used it for Pauropoda and for small Pycnogonida. Zoologists should be able to extend its use to other groups, for example, Crustacea (after decalcification if necessary) and perhaps Polychaeta and Nematoda.

The writer is indebted to Dr. J. Davidson for placing at his disposal his early notes relating to this mountant, and for reading through the manuscript. He is also indebted to Mr. H. Womersley, of the South Australia Museum, for details of his experience with it.

References.

ELTRINGHAM, H. (1930). Histological methods for entomologists, p. 91.

GATER, B. A. R. (1928). Bull. Ent. Res. **19**, p. 367.

IMMS, A. D. (1929). *Ibid.* **20**, p. 165.

LEE, A. BOLLES. (1921). Microtomists' Vade-Mecum 7th ed., p. 504 ; do. (1924) 8th ed., p. 504 ; do. (1928) 9th ed., p. 515.

SEIDELL, A. (1928). Solubilities of inorganic and organic compounds, 2nd ed., p. 1164.

ON THE CONTROL OF HOUSEHOLD ANTS.

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Introduction.

The writers, as a result of numerous enquiries during recent years, have had opportunity of making observations on the control of various species of ants which invade houses. In the majority of cases the species involved was *Monomorium pharaonis*, L., commonly known as Pharaoh's Ant or the Red Ant. One case of infestation by *Acanthomyops* (*Donisthorpea*) *niger*, L., was dealt with and is discussed later. Householders also sometimes complain about out-door species, the workers of which wander in small numbers into houses, particularly if the nest is near the house. The species *Myrmica ruginodis*, Nyl., for example, has been the cause of complaint of this kind by nesting under stones or the doorstep, and from this site slight sporadic, perhaps accidental, invasions of the house have occurred, causing annoyance to the householder. This account deals largely, however, with Pharaoh's Ant the most widespread and serious household ant pest.

The writers have encountered this pest in dwelling houses, hotels, factories, restaurants and hospitals. The life-history and habits of this species have been described by many observers in all parts of the world. Donisthorpe[1] gives an account of the species and its occurrence in this country and Smith[2] gives a useful summary of American literature on the species and its control. It is only necessary, therefore, to include a brief account of the writers' observations on the occurrence and habits of the species in so far as they affect a consideration of control measures.

Pharaoh's Ant is in this country a true indoor species and being heat-loving its nests are found in heated premises. Donisthorpe, MacDougall[3] and the American workers (*vide* Smith) state that the ant makes its nest in the foundations, in walls, under floors and behind ovens and boilers. In all cases in the writers' experience, the nests have been located in places hidden behind or very near to places like kitchen ranges or boilers. From these nests the workers in foraging range all over the premises, and the rough position of the nest can be gauged by observing the swarms of workers which in going to and from the nest tend to keep to the same tracks. The workers in fact, often make actual paths which may be discerned on a light-coloured wall or on a tiled surface.

The enormous numbers of workers emitted from a well established colony is frequently referred to in the literature, and Donisthorpe (quoting Bellevoye) describes the capture, during a period of four months, of 1,360,000 workers in addition to a number of females and males.

Foodstuffs of all kinds are very attractive to the foraging workers and such materials left exposed are soon literally swarming with the insects. Their minute size renders it difficult to exclude them even from tightly closed containers. The writers have frequently met with cases where cakes and other eatables stored in tins and wrapped chocolates stored in boxes, on being opened for the first time were badly infested and thereby rendered unfit for consumption. Food storage in hospitals and similar large institutions soon becomes a very acute problem, which is insoluble as long as the infestation remains.

Pharaoh's Ant, as other workers have observed, feeds on a variety of substances, its food list includes not only sweetstuffs but also meat, fat, dead insects and many other materials.

A colony, therefore, allowed to remain unchecked rapidly renders a house or other premises almost uninhabitable, not only because of the contamination of foodstuffs, but also on account of the psychological effect on the inhabitants when their premises are overrun by these annoying pests. It is felt, therefore, that the following brief account of the writers' experience on the control of these insects may be a useful addition to our knowledge of the control of household pests.

The general opinion among those who have studied Pharaoh's Ant is that it is far from easy to exterminate. Donisthorpe states that it is almost impossible to rid premises of a well-established colony. This difficulty depends first on the insect's habit of forming its nest in places difficult to reach without the expense and trouble of dismantling parts of the building in which the nest is situated.

Another factor rendering control difficult is the fact that there may be several queens in a colony and a huge proportion of workers. The character of the premises infested also affects the nature of the control methods possible, for it is obvious that in a small dwelling-house the chance of dealing effectively with an infestation is greater than in the case of a mansion or an establishment like a hospital or a hotel.

Destruction of the Nest.

Destruction of the nest where practicable, as for instance in small houses, is the most certain method of exterminating Pharaoh's Ant. In the writers' experience this has involved the removal of the kitchen range, unearthing the nest and treating it with boiling water and spraying it with paraffin or some other suitable contact insecticide. One interesting case dealt with in 1933 may be quoted in this connection. A row of six small houses were all infested to such a degree that no foodstuffs were free from the insects. The inhabitants were forced to live largely on tinned foods and to consume them immediately they were opened, and foods like bread and cakes were bought in quantities suitable for immediate consumption. Observation of the movements of the workers suggested that the infestation was centred in a single nest situated in one of the houses. The workers were streaming to and fro by way of cracks and crevices round the kitchen range. The range was removed, the nest found in the wall behind and destroyed in the manner described. No recurrence of the ants has taken place after a lapse of over two years.

Trapping.

The commonest control method adopted against household ants is to place in infested premises sponges soaked in sugar solution or syrup. The ants are readily attracted in numbers and by dropping the sponges into boiling water large numbers are killed. The writers' experience shows that in cases of small infestation this method if persisted in may give a large measure of control by reducing very considerably the numbers of workers. In no case however has extermination resulted from this practice. In the case of large well-established colonies the palliative character of the method is emphasised. Donisthorpe states that the method gives only a temporary relief. Smith summarises the American opinion on this method, which in some cases seems to have given satisfactory results, but apparently it cannot be relied upon to give complete control in all cases.

Insecticides.

Cases have been met with where inhabitants have tried proprietary sprays against the workers, but the most that can be said of this measure is that it gives a reduction in numbers of ants at the time of spraying. The same may also be said of certain insect powders in common use. Borax has not been found effective in controlling these ants.

Poison Baits.

In 1932 an editorial summary[2] on the control of ants in foodstuff businesses in Germany gives a brief account of measures suitable for adoption against Wood Ants, *Lasius* (*Acanthomyops*) spp., and Pharaoh's Ant.

In the case of the latter species it is stated that the only sure method of control is location and destruction of the nest, since baiting, which is effective in the case of the Wood Ants, is useless against Pharaoh's Ant. The baits suggested against Wood Ants are syrups poisoned by one of four substances, namely, arsenious oxide, chloral hydrate, tartar emetic or lead arsenate.

Smith refers to the various American methods of poison baiting involving the use of tartar emetic, arsenical compounds such as sodium arsenite, mixed with syrup or fat. The opinion appears to be that tartar emetic is superior to arsenical compounds in syrup baits. The writers have no experience of the use of tartar emetic, and they have purposely refrained from using arsenical compounds in household and other premises in view of the possibility of poisoning human beings and pet animals. They have had opportunity, however, of making trials of the thallium sulphate-syrup method introduced in America by Popenoe[5] and used by Cotton & Ellington[6]. The method adopted by the writers was that described by the latter workers who designed a simple container for the poisoned syrup. Similar containers (fig. 1) were used by the writers in cases described below. Directions for making these are quoted from Cotton & Ellington as follows :—

"The container for this ant poison consists of an ordinary pill box the interior of which has been washed with a solution of hot paraffin wax to make it water tight. Four small sections of cardboard are removed from the inner circular collar over which the top or cap of the pill box fits. When the container is in use the top of the pill box is partially raised, exposing four small openings where the cardboard has been cut away and through these the ants can enter to obtain the syrup."

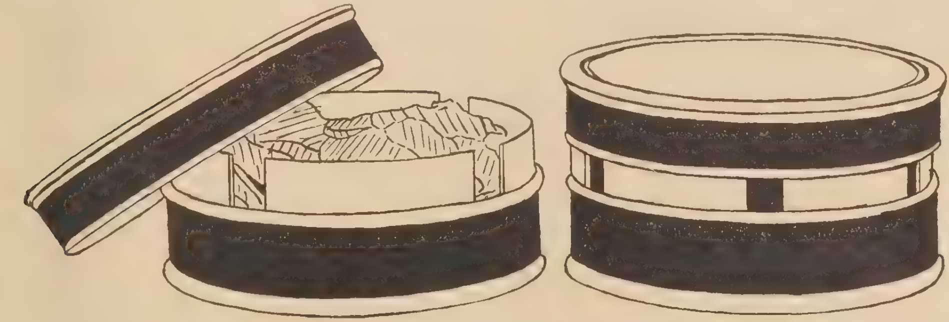

Fig. 1. Ant traps used in the thallium sulphate-syrup poison bait method. Box on the left with lid removed to show contents. Box on the right with lid in position ready for use.

The poisoned syrup is made up in the following proportions :—

Water	1 pint
Sugar	1 lb.
Honey	3 oz.
Thallium sulphate	27 grains.

The ingredients are thoroughly mixed together and brought almost to boiling point, care being taken not to breathe in the vapours when stirring the heated mixture.

The containers are two-thirds filled with pieces of blotting paper and then a small quantity of poisoned syrup is added to moisten the paper thoroughly.

The writers first tried this method in 1934 in a large country mansion which had been infested by Pharaoh's Ant for a number of years, and the result was completely successful. Prior to the poison baiting the owner had made many attempts to stop the infestation. He had persisted in the use of the sweetened sponge method by means of which he destroyed large numbers, but the workers continued to invade every part of the house, and food anywhere on the premises had only to be exposed for a brief time for it to become covered with the insects.

The house is centrally heated, but observation revealed that the nest was in the vicinity of the kitchen range. Removal of the range in this establishment would have involved very considerable expense, so that the owner willingly co-operated in a trial of the thallium sulphate-syrup. Two dozen boxes were used and were placed in the kitchen and associated rooms. After the first few days the ants, which had been readily attracted to the boxes, seemed decidedly less numerous. After ten days had elapsed it was possible to leave food exposed without much fear of infestation. During the second week a few workers could be found, more particularly in places distant from the kitchen. It can be stated definitely that within three weeks this old-established colony had been completely wiped out, and no recurrence of the trouble has been experienced. The amount of bait used in this case was about one pint, and the cost of boxes and materials is estimated at about half-a-crown.

Another case which may be quoted involved a very serious infestation of the main service block of a mental hospital which was literally overrun by the swarms of workers of *Monomorium pharaonis* and entailed the usual acute discomfort to staff and patients. The large kitchens, food stores, dining rooms, living rooms, in fact every room in the main block, were infested. Cooked food unless immediately consumed was quickly infested and rendered inedible. Sugar, flour and the like stored in large bins were always infested, and the position was rapidly becoming intolerable. The writers found that the seat of infestation was in the large kitchen, and it seemed certain that the nest was hidden somewhere in the structure supporting the large ovens. Removal of the ovens would have involved relatively enormous expense and would have seriously interfered with the normal running of the establishment. The thallium sulphate method was therefore introduced. Two dozen boxes were placed in suitable positions in the kitchen and other rooms and the superintendent arranged for a member of his staff to inspect the boxes at frequent intervals and renew the baits when necessary. There was a perceptible reduction in numbers during the first week of baiting, and within a month the infestation appeared to be restricted to the kitchen and adjacent boiler-house and even here the numbers of ants were very small. Before baiting very definite tracks made by the streams of foraging workers were clearly seen on the tiled walls of the kitchen, and some idea of the reduction of the infestation may be gained from the fact that after the first few weeks these paths no longer recurred. It was soon possible to allow food to lie in the dining rooms and other outlying rooms without fear of contamination. From this time onwards the degree of control progressed slowly, and investigation suggested that the delay in effecting complete control was related to the fact that the syrup in the boxes in the kitchen quickly dried up on account of the comparatively high temperature in the vicinity of the range, where many of the boxes were placed near points where the ants emerged. Ultimately complete control was apparently obtained by using the bait more liberally in each box and examining and renewing the contents more frequently.

A third case illustrating the value of this method is quoted with reference to another species of ant, namely, *Acanthomyops* (*Donisthorpea*) *niger*, L. A small town house was infested by a two-year-old colony of this species. Borax and insect powders had proved of no avail against the workers, which were very numerous in the kitchen and pantry and appeared to enter the house through the party wall between the house in question and the adjoining dwelling. It was thought that the nest may have been in the foundations near the party wall. Four boxes suitably baited were placed in the pantry and within an hour they were black with the insects. Within two days the ants had all disappeared and there has been no recurrence of infestation after the lapse of about a year.

The cases quoted above show that Popenoe's method elaborated by Cotton & Ellington is worthy of extensive trial in this country. It involves inappreciable expense, no structural alterations to premises, and if used in the manner described offers little chance of danger of poisoning to man or animals. The boxes can be placed out of reach of children when necessary. The writers suggest that in cases where householders fear any danger, the bait should be used in tightly closed tins into which small holes are punched.

Acknowledgments.

The writers are indebted to the Keeper of Entomology at the British Museum and to Mr. H. St. J. K. Donisthorpe for identification of specimens of ants.

Summary.

1. Methods of controlling ants invading houses are discussed.

2. Various methods have been tried, particularly against *Monomorium pharaonis*. The more general methods in use such as syrup baiting and the use of various insecticidal powders and sprays show at best a palliative effect and do not exterminate the pest. Destruction of the nest is effective where it can be carried out.

3. The use of a thallium sulphate-syrup as a poison bait devised by Popenoe has been tried with success against *M. pharaonis* and *A.* (*Donisthorpea*) *niger*. This inexpensive method is likely to prove useful in places where it is not practicable to find and destroy the nest, which invariably involves considerable structural alterations.

References.

[1] Donisthorpe, H. St. J. K. (1927). British Ants. George Routledge & Sons, Ltd., London.

[2] Smith, R. C. (1933). A summary of published information about Pharaoh's Ant.—Trans. Kans. Acad. Sci. **37.**

[3] MacDougall, R. S. (1929). Insect enemies of 1928.—Trans. Highl. Agric. Soc. Scotland, **41.**

[4] Anon. (1932). The control of ants in foodstuff businesses.—Mitt. Ges. Vorratsschutz. **8.**

[5] Popenoe, E. A. (1926). Thallium sulphate as a poison for ants.—Science, **64,** No. 1,665.

[6] Cotton, R. T. & Ellington, J. W. (1930). A simple and effective ant trap for household use.—J. Econ. Ent., **23.**

EXPERIMENTAL STUDIES ON LOCOMOTOR ACTIVITIY IN *LOCUSTA MIGRATORIA MIGRATORIOIDES*, R & F.

By K. H. L. Key, M.Sc., Ph.D., D.I.C.

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Introduction.

Work on locusts, especially by Faure, has indicated the importance of excessive muscular activity in the formation of phase *gregaria* in these insects. With the exception of the work of Bodenheimer, however, no attempt has been made to study locomotor activity experimentally in locusts. What is needed is a method which will enable us to compare the locomotor activity of an isolated individual with that of a marked individual in a crowd. The present investigation was designed to explore the possibilities of such a method with a view to its ultimate application to this problem, and in the meantime to use the method to obtain a general idea of the quantitative aspect of locomotor activity and some of the factors which influence it, in phase *solitaria*.

The literature on locomotor activity is so extensive, and the subject has been approached from so many angles, that to do justice to it would be impossible in a paper of this length. A thorough survey of the published work is contained in my thesis for the London Ph.D., of which this paper is a condensation, and which is available for consultation in the library of the University of London.

The present study is concerned entirely with what is known as "spontaneous" activity, *i.e.*, with the activity which persists when stimulation from without has to all intents and purposes been eliminated. This idea of "spontaneous" activity is a relatively new one, and the work which has been done on the subject is not so widely known as it might be. It is well summarised by Richter (1927).

Material.

The material used in the experiments to be described was derived from a stock of *Locusta migratoria migratorioides* which has been bred for over ten generations by the Imperial Institute of Entomology in its research laboratory in London. The insects came in the first place from Central Africa. No special stock was started for the purpose of these experiments, but batches of just-hatched hoppers were received from the Institute as they became available, and were immediately placed in the constant-temperature room in which all the work was done, and were maintained under conditions as nearly constant as it was possible to obtain. The constant-temperature room maintained a very uniform temperature of 27°C., and was lighted continuously. Each hopper was isolated in a desiccator of about 10 cm. internal diameter and about 6 cm. high, with a perforated zinc partition separating the upper from the lower chamber, and was placed in a well-lighted position.

Some insects were reared under wet, some under dry, conditions by placing either water or $CaCl_2$ in the bottom of the desiccator, and using a well-fitting and slightly-greased lid. In this way relative humidities varying between 5 per cent. and 20 per cent. were obtained. It is impossible to maintain a constant low humidity in cages containing insects which have to be fed on green food, but if not too much food is given, this soon dries up, and the humidity falls within a few hours to its original low value. Insects "reared dry" in the following account, then, have been kept at a humidity of, on the average, 5–10 per cent., with a rise about once a day to about 50 per cent. for a few hours. The relative humidity in the "wet" cages reached over 99 per cent., and must frequently have been at saturation.

The problem of ventilating these cages was solved by removing each lid for an hour each day at the time of feeding; the original humidity was quickly resumed when the lid was replaced. The food consisted of cut grass brought in each day from the country.

Under such completely isolated conditions it is clear that only phase *solitaria* could develop, and this was confirmed by the records of the colour characteristics of the hoppers and the structural characteristics of the adults, of which records were kept. Records were also kept of all relevant factors in the life of each insect, such as date of moults, abnormalities, signs of indisposition, and date of death. No activity determinations were made on the day preceding or following a moult—in the last two instars, on the *two* days preceding or following a moult. Mortality was very high under the conditions employed in the C.T. room. Not more than 12 per cent. of the first instar nymphs became adult, and most of those died within a week or two of becoming adult.

The determination of relative humidity in the cages, and in the activity apparatus to be described, was carried out by means of the Edney Paper Hygrometer by the method described elsewhere (Key, 1936a).

Technique.

It was desired that the form of apparatus adopted for the measurement of the total amount of activity should be applicable not only to isolated individuals but eventually also to crowds. It was found impossible to devise any automatically recording apparatus which would register the activity of one individual in a crowd, so recourse was had to the method of direct observation of the distance travelled in a special cage in a given time. The cage was constructed in such a way that relative humidity and light intensity could be controlled and measured, and all stimuli eliminated ; the whole apparatus was operated in the constant-temperature room at 27°C., and the temperature inside the apparatus was measured.

Apparatus.

The main part of this apparatus consisted of a large accumulator jar (J, figs. 1 and 2), 29·5 cm. long and 21·5 cm. wide, in the middle of the bottom of which a hole had been bored to take a rubber stopper carrying a thermometer (T) and hygrometer (H). A cage of $\frac{3}{4}$ in. mesh wire netting covered all over with black cotton netting of about $\frac{1}{8}$ in. mesh was then made, of such a size as to fit exactly inside the glass jar. The floor (F) of this wire cage consisted of a thin wooden frame covered with perforated zinc, with a door (D) opening outwards and large enough to admit the hand. This floor was at such a depth that when the wire cage was pushed right into the glass jar, it lay at a distance from the bottom of the jar which was equal to the width of the jar (21·5 cm.). Several inches of the jar protruded beyond the floor. The whole apparatus thus constituted was designed to be inverted in a large dish (fig. 2, P) containing either water or a few small dishes of $CaCl_2$, the floor being well raised above the surface of the water or drying agent. In this position the bottom of the accumulator jar becomes the top or roof of the cage, and is referred to as such in the following.

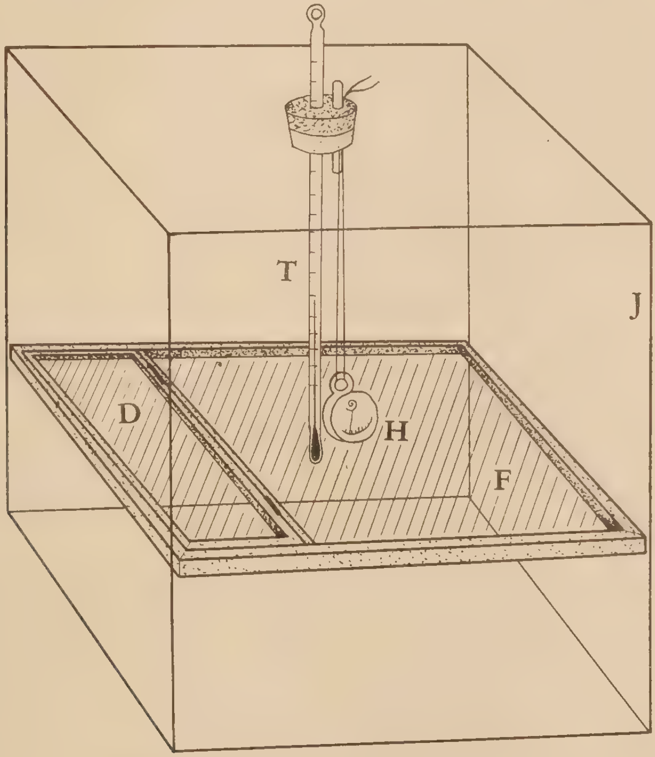


Fig. 1. Activity apparatus : F, floor ; H, hygrometer ; J, accumulator jar ; T, thermometer ; D, door.

The essential part of the apparatus thus consists of a glass chamber in which humidity can be controlled, lined with cotton netting, and with a perforated floor containing a door. The cage being of glass enables light to be admitted, while the function of the cotton netting is to enable the locusts to obtain a foothold on the sides and roof. This chamber, 29·5 × 21·5 × 21·5 cm., had each of its six sides divided up into 25 squares by means of thin white lines painted on the outside of the glass. This gave two kinds of patterns—the front and back of dimensions 29·5 × 21·5 cm., and the top, floor and ends of dimensions 21·5 × 21·5 cm. Charts of these two types of sides, with their squares, were drawn to half scale, and many copies made by cyclostyling. The course taken by the experimental insect inside the cage was traced out on these charts in the manner described below.

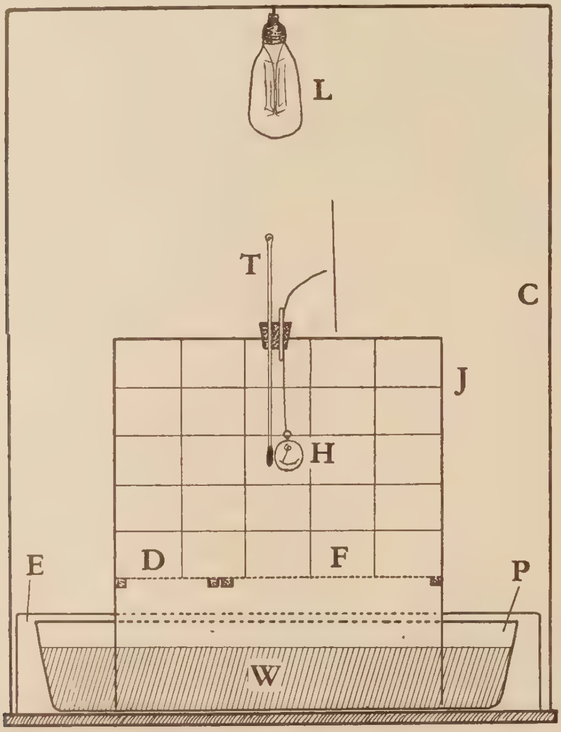


Fig. 2. Diagrammatic vertical section through activity apparatus prepared for a determination: C, cardboard cover; D, door; E, cardboard cover to prevent evaporation; F, floor; H, hygrometer; J, accumulator jar; L, electric light bulb; P, dish; T, thermometer; W, water.

Evaporation from that part of the water surface in the dish (P) which was exposed to the air outside the cage walls was found to reduce the temperature of the whole by one or two degrees, so a cover made of cardboard was fitted right round the cage to reduce this evaporation (fig. 2, E). Finally, the question of lighting had to be considered. It was essential to provide lighting of constant intensity and direction. As the C.T. room was being used by other students, it was also essential that the insect inside the cage should be protected from the stimulation of moving objects. A large cardboard cover (fig. 2, C), painted black inside, was therefore placed over the apparatus during an experiment. This cover bore a Mazda 30-watt electric light bulb (fig. 2, L) in the centre of the roof at such a distance from the cage that the heating effect from it was very slight. (Actually the rise in temperature inside the apparatus during the course of a determination, which lasted altogether an hour, amounted to about 1°C.) The light intensity in the middle of the cage, *i.e.*, after the light from the bulb had passed through the glass and netting—was measured by means of a Holophane Lumeter and found to be 3·6 ft.-cands.

When water was used in the dish (P) the R.H. in the cage reached a value after a few days which did not differ from saturation by any quantity which could be measured. Occasional removal of the rubber stopper for the purpose of inserting an insect did not noticeably affect the R.H. Removing the cage from the water for the purpose of removing an insect reduced the humidity, but a value very near to saturation was restored within a few hours of its return to the dish, and by the next day the atmosphere was again quite saturated. After the length of time required for the original humidity to be restored had been discovered in this way, no hygrometer was included in the apparatus when " wet " determinations were being made. For " dry " determinations, four dishes of granular calcium chloride, about 9 cm. in diameter and 1 cm. deep, were placed in the large dish under the cage, and a hygrometer was always used, because the drying agent was liable to deteriorate, and the cage was not sealed from the air, as was the case when water was used in the dish. In this way humidities varying between 5 per cent. and 20 per cent. R.H. were obtained in the cage.

The whole apparatus stood on a table in a position in which it was protected from jolts, and great care was taken during a determination not to jar the apparatus in the slightest. Observation of the movements of the insect within the cage was made through a small opening in the large cardboard cover right opposite the centre of the front of the cage. The light inside being much brighter than that outside made it unlikely that the insect would be disturbed by slight movements of the observer seen through this opening.

Method of Procedure.

In making a determination of the distance travelled inside the apparatus a definite schedule was always rigidly adhered to. The apparatus had first to be prepared, *i.e.*, it had to be seen that the required humidity obtained, and that all the instruments were registering properly. The exact times were then worked out at which four essential processes had to be carried out. These were :—

1. Feed insect.
2. One hour later : remove all food.
3. Four hours later : " equilibrate " insect.
4. Thirty minutes later : carry out determination.

1. The insect having been left in the presence of food for an hour had presumably had ample opportunity to feed, if hungry. This was important, since in the case of insects which had been reared in " dry " cages it was quite likely that the food had long dried up and become unappetising.

2. The period of four hours without food was designed to produce a more or less constant degree of hunger in all the insects used. If insects were used immediately after they had had access to food, some might have been feeding at the moment they were removed, while others might not have taken any food for the preceding half-hour ; as between two such insects there would be likely to be a greater difference in activity—if activity is affected by nutritional condition—than between two insects, one of which had gone four hours, and the other four and a half hours, without food.

3. " Equilibration " of the insect consisted in placing it in the apparatus, putting on the cover, and leaving it undisturbed for half an hour before starting the actual determination, in order to give it an opportunity to become accustomed to the new conditions, and, particularly, to recover from the mechanical stimulation incidental to its insertion in the apparatus. It may be argued that we have no reason for thinking that this length of time is sufficient for this purpose. On the other hand, the only way of finding out would be by means of some kind of activity

determination, such as the one which is being attempted, while it may at least be said that all the insects have had the same opportunity to recover from the shocks of handling. From superficial observation it appears that a *solitaria* hopper shows no signs of excitement within as short a time as a few minutes of being handled, so that probably half an hour is ample.

Finally, we come to the exact method of making the activity determination. The opening in the light cover is of such a size that the insect inside the cage can be observed in whatever position it takes up. The position of the head is taken as representing the position of the insect, and its progress across the squared surfaces of the cage is recorded on a copy of the chart by tracing its path with a pencil. At first distinction was made in the method of recording between movement on the various internal faces of the apparatus. Later, no distinction was made (see below). All relevant data concerning the insect used and the experimental conditions were recorded on each chart. Owing to lack of material the same insect had to be used in a number of determinations in different stages and in the same stage, but, where possible, the same insect was not used on successive days. About fifty insects were used altogether. Jumps were extremely rare (p. 418) and were specially indicated on the record.

The activity was recorded for exactly 30 minutes, and then the experiment was discontinued, the insect removed and returned to its living cage, and the activity apparatus prepared for the following determination. Temperature and humidity readings were taken immediately before equilibration and immediately after the determination.

Method of Treatment of the Experimental Results.

The length of the path followed by the insect, as recorded on the chart, was measured by stepping it off in cms. with dividers, and divided by 30, which gave the average distance travelled per minute in the half-hour period. This figure, cms. travelled per minute, forms the basis of all the subsequent discussion. It should be noted that it is a measure, not of speed, but of total distance travelled in a given time, which is taken to be an index of total activity.

At first distances walked horizontally and vertically were separately calculated, and the vertical distances were separated into distance walked upwards and distance walked downwards. The existence of both horizontal and vertical walking seemed at one time to present a serious difficulty in interpreting the experimental results. The alternative of keeping all the activity on the horizontal by means of slippery glass sides was considered, but rejected, since much energy would be expended in trying to climb the sides, and this activity could not be registered in terms of distance travelled. It is clear that progression upwards involves an output of energy many times greater than progression on the level. Just what relation exists between these amounts could be calculated if we knew the weight of the insect considered, and the frictional resistance it experiences in walking. The former quantity can easily be determined, but no method of estimating the latter is known to the author. The distance travelled upwards can obviously never differ from the distance travelled downwards by more than the height of the cage, so that whenever there is any considerable amount of vertical walking, the distances upwards and downwards may be considered equal ; however, travelling downwards cannot be held to balance in any effective sense an equal amount of travelling upwards. In travelling in any hanging position, *i.e.*, inverted from the roof, horizontally along a vertical plane, or downwards on a vertical plane, a certain tension of the leg muscles is required to prevent the insect from falling ; in travelling along the ground a similar tension of about the same magnitude is required to hold the body above the ground ; the amount of energy expended in walking downwards is quite comparable to that expended in horizontal walking. Thus we cannot regard the weight of the insect as " helping " it in any way in walking downwards, and thus compensating for the difficulty of lifting that weight in walking upwards.

A further difficulty in attempting to find a common basis for dealing with vertical and horizontal walking consists in the fact that the insect is subjected to very different stimulating forces according to whether it is walking upwards or on the level. On the level it is free from geotropic excitation, and the light is almost immediately above it ; as soon as it starts to climb the sides it is free to react to gravity, and the light is approximately ahead of it. It seems quite impossible to make any allowance for this change in the stimulating effect of the environment, which must be considerable, and without making such an allowance it would be futile to correct for the work done in lifting the body in upward walking, even if the friction factor could be determined.

In spite of these difficulties it was decided to proceed with the work, in the expectation that differences in activity under different conditions would become apparent in spite of the heterogeneous composition of the measure "distance travelled." That this expectation was justified will be seen when the results are discussed. The proportion of upward walking is in any case small, varying for the most part between 0 per cent. and 20 per cent. Only when the activity is below 100 cm. per half-hour, or 3 cm./min., does this proportion rise above 20 per cent. Moreover, there are sufficient records in which all the activity is on the roof to show that the extreme dispersion referred to on p. 417 is independent of the amount of vertical walking.

So far as possible equal numbers of determinations were made on each instar, on each sex, and under each set of conditions used.

Variability from Period to Period, and Individual Variation.

The most outstanding feature of the activity figures obtained by the methods discussed above was the very high degree of variability in the results obtained in different determinations, even from the same insect, reared and tested under identical conditions. Thus hopper No. 14, a male in the fifth instar, gave the following figures on three different days (in cm./min.) : 140, 5, 32. This state of affairs was quite typical of all the insects used in the determinations. Sometimes a particular hopper would give a succession of high or low readings, which seemed to mark it out as a particularly active or inactive individual, but this was not usually the case, and was often connected with some pathological condition of the individual concerned. Thus the great variations observed in the figures given in Tables I and II are to be ascribed, not to individual differences, but to alternating periods of high and low activity. Such variations are not unexpected in view of what is already known of the rhythmic character of locomotor activity in many animals, even under constant conditions (Richter, Szymanski, etc.).

General Distribution of Activity.

In view of the great differences in the activity readings, the average under any given set of conditions has little meaning, and therefore the method was adopted of plotting frequency diagrams, showing the percentage of cases in which activity of different grades was exhibited. The effect of different conditions upon activity was studied by comparing the frequency or distribution curves obtained under each set of conditions.

Fig. 3 shows the distribution curve obtained when all the available data are included, irrespective of the conditions under which they were obtained. This procedure is justified, since, as will appear, the curves did not differ greatly under any of the conditions employed. Along the horizontal axis are marked off activity groups, each comprising a range of 5 cms./min., and along the vertical axis the percentage of all the records falling in the various activity groups. The figures from which this frequency diagram was constructed are given in Table I. From this it will appear that 69·9 per cent. of the records showed an activity in the 0–5 cm./min. group, while 30·1 per cent. showed an activity of more than 5 cm./min.

TABLE I.

Distribution of all the available Records.

Group	cm./min. Range	No.	Percentage
1	0–5	114	69·9
2	5–10	23	14·1
3	10–15	15	9·2
4	15–20	5	3·1
5	20–25	3	1·8
6	25–30	2	1·2
7	30–35	1	0·6
Totals		163	99·9

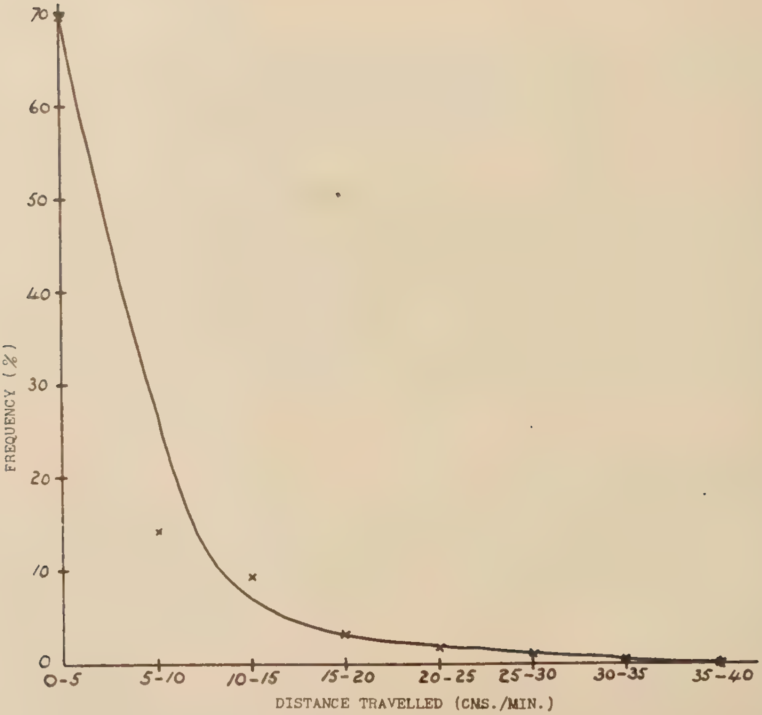


Fig. 3. Distribution curve of the activity of *Locusta*. Different activity grades are plotted along the abscissa (in cms./min.), and the frequency with which these activity grades occur, along the ordinate. All available records used (Table I).

The percentage of records falling in the higher groups shows a regular decrease, only one record (0·6 per cent.) falling in the group 30–35 cm./min., and none in groups higher than 35 cm./min. The preponderance of very low activity is very definite.

The maximum of this curve, *i.e.*, the mode, lies, clearly, in the 0–5 group. The records falling in this group and the 5–10 group were therefore analysed further, in order to define more precisely the position of the mode. The results of this analysis are shown in fig. 4 and Table II. The material comprising the first two groups of

TABLE II.

Analysis of Groups 1 *and* 2 *in Table I.*

Group	cm./min. Range	No.	Percentage
1	0–1·4	84	60·9
2	1·4–2·9	19	13·8
3	2·9–4·3	8	6·0
4	4·3–5·7	7	5·1
5	5·7–7·1	11	8·0
6	7·1–8·6	6	4·4
7	8·6–10·0	3	2·2
Totals		138	100·4

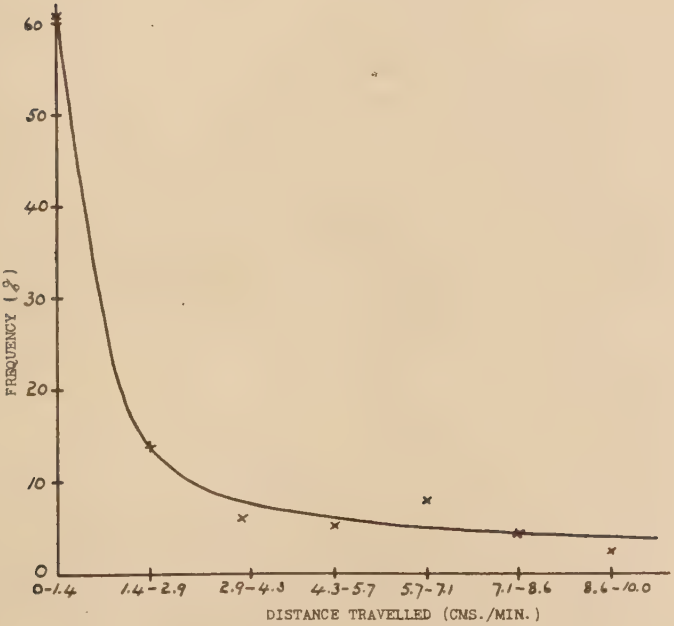


Fig. 4. Further analysis of the distribution of activity up to 10 cm./min. (Table II).

Table I was divided into seven groups, *i.e.*, the same number of groups used in Table I and fig. 3, in order to facilitate comparison of the curves obtained. The curve in fig. 4 is remarkably similar to that in fig. 3; again the maximum, representing the mode, falls in the lowest group, 0–1·4 cm./min.; its value is again much greater (60·9 per cent.) than the percentages in all the other groups taken together, and the percentages in the second and third groups, respectively, are of the same order as in fig. 3; the percentages in groups 4–7, however, are somewhat higher than in the corresponding groups in fig. 3.

In Table III and fig. 5 a further analysis of the 0–1 cm./min. group has been undertaken, using again seven groups. This time the curve is of a different form; it is much flatter and the percentage in group 1 (38·4) is less than the combined percentage in the other groups (61·7). The percentage in the lowest group, however, is still twice that in any other single group: the mode is still in the lowest group. The total number of records in which there was absolutely no activity is 19, which is 67·9 per cent. of the number in the 0·0–0·14 group in Table III. There are not sufficient records to enable a complete analysis of the activity below 0·1 cm./min., but it is clear that the distribution curve in this region resembles more closely the curves in figs. 3 and 4 than that in fig. 5.

TABLE III.

Analysis of Group 0–1 *cm./min.*

Group	cm./min. range	No.	Percentage
1	0·0–0·14	28	38·4
2	0·14–0·29	14	19·2
3	0·29–0·43	12	16·4
4	0·43–0·57	7	9·6
5	0·57–0·71	3	4·1
6	0·71–0·86	4	5·5
7	0·86–1·00	5	6·9
Totals	... ...	73	100·1

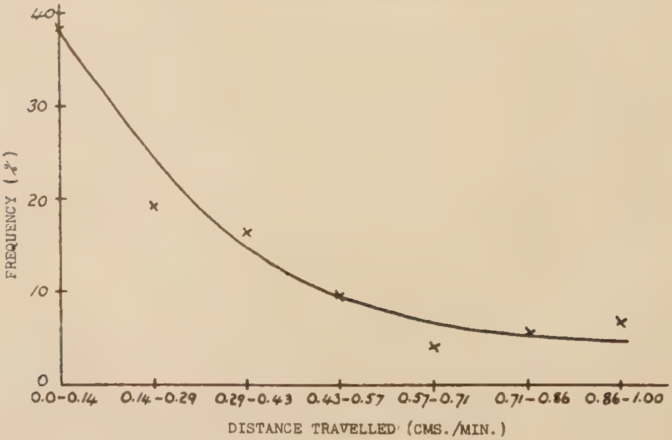


Fig. 5. Further analysis of the distribution of activity up to 1 cm./min. (Table III).

From the above considerations it must be concluded that the activity mode is zero, that is, complete rest. Very low activity, below 0·1 cm./min., is rare, *i.e.*, once activity falls below 0·1 cm./min. complete rest is by far the commonest condition. If we consider activity up to 1·0 cm./min., the frequency is more evenly distributed, and most of the activity falls outside the lowest group. Above this activity level, again, whether we consider the whole range of the records, or the first two groups alone, most of the activity is in the lowest group.

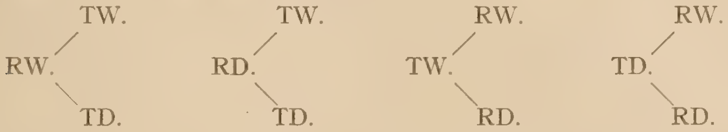
In comparing the frequency curves obtained under different conditions, the figure for the percentage in group 1, or the combined percentage greater than group 1 will be mostly used. These percentages are, of course, the most reliable since the numbers in the individual groups above 5 cm./min. are small.

For the further interpretation of the above conclusions we require to know something of the distribution of activity during the 24-hour cycle. The conditions in the C.T. room were absolutely constant from the time when the first instar nymph was first placed inside it, and reflected none of the external changes associated with the alternation of day and night. Under these conditions we should expect that the activity, though periodic, would not be related to the time of day, *i.e.*, that it would be equally probable that a period of high activity would occur at noon, midnight, or any other time of day or night. This has been shown to be the case by Mr. E. Berry Edney in unpublished experiments with the "actograph," carried out in the same C.T. room as the present experiments and under identical conditions.

Thus we may go further and say that 70 per cent. represents not only the probability that a half-hour activity record will fall in the group 0–150 cm./½ hr. (0–5 cm./min.), but that it represents the probability that an insect, under the conditions of the experiment, will show this amount of activity in any half-hour of the 24; in other words, it is a measure of the proportion of the insect's time which it spends in activity of an intensity of less than 150 cm./½ hr.

Relative Humidity and Activity.

The effect of humidity upon activity has been investigated from two points of view. The effect has been considered of high and low humidities during the whole developmental period, and of such humidities during the activity determination alone. Thus with respect to humidity the records may be divided into four categories: those referring to insects "reared wet," "reared dry," "tested wet" and "tested dry." In the following these conditions are referred to as "RW," "RD," "TW" and "TD," respectively. The exact meaning of the terms "wet" and "dry" is explained in the sections on "Material" and "Technique" (pp. 400–403). Insects which had been reared wet could be tested either wet or dry, and the same applies to insects reared dry. Similarly, insects tested wet may have been reared either wet or dry, and the same applies to insects tested dry. The possible combinations may be expressed diagramatically as follows:—



(1) *The effect of wet and dry conditions during the determinations* (*TW., TD.*).

Table IV presents separately the figures for the distribution of activity of instars 3–5, tested wet and tested dry (TW. and TD.). In each case almost equal numbers of the two sexes were used, the ratio between the numbers RW. and RD. was the same, *viz.*, 2 : 1, and the ratio between the numbers of each instar used was almost the same. The exact composition of the material used is indicated at the head of the table.

In the first and second instars it is assumed that, since the sex differences are so slightly developed, these differences will not have any effect upon activity, and need not be taken into account. Table V gives the figures for TW. and TD. in the first two instars combined, equal numbers of each being used. All the insects used were RW., since it is impossible to rear the first two instars at very low humidities.

TABLE IV.

Composition of Material used.

T.W.	TD.
♂♂ : ♀♀=19 : 17	♂♂ : ♀♀=26 : 24
RD : RW=12 : 24	RD : RW=17 : 34
3rd : 4th : 5th=21 : 35 : 28	3rd : 4th : 5th=20 : 35 : 30

Group	cm./min. range	TW.		TD	
		No.	Percentage	No.	Percentage
1	0– 5	34	66·7	25	69·4
2	5–10	7	13·7	6	16·7
3	10–15	5	9·8	4	11·1
4	15–20	2	3·9	0	0·0
5	20–25	1	2·0	1	2·8
6	25–30	2	3·9	0	0·0
7	30–35	0	0·0	0	0·0
Totals ...	...	51	100·0	36	100·0

TABLE V.

Composition of Materials used :—Equal numbers of 1*st and* 2*nd instar hoppers, all R.W., sex ignored.*

Group	cm./min. range	TW.		TD	
		No.	Per-centage	No.	Per-centage
1	0–5	12	60·0	15	75·0
2	5–10	2	10·0	3	15·0
3	10–15	4	20·0	1	5·0
4	15–20	1	5·0	1	5·0
5	20–25	1	5·0	0	0·0
6	25–30	0	0·0	0	0·0
7	30–35	0	0·0	0	0·0
Totals ...	...	20	100·0	20	100·0

If we consider the figures in these two tables we see that whereas the distribution in Table IV, referring to instars 3–5, is the same for TW. and TD., the percentages in group 1 being not significantly different, in Table V, referring to instars 1 and 2, the percentage in group 1 is higher in the case of TD., *i.e.*, the activity under dry conditions is less in these instars. There is one important difference, however, between the material used in the two tables besides the instar difference : in Table IV one-third of the material was RD., while in Table V all the material was RW. An analysis was therefore made of the 3rd–5th instar material, using only the RW. records. This analysis is presented in Table VI. In this case the percentage in group 1 is somewhat less for TD. than for TW.—the opposite of what was found for instars 1 and 2 when only RW. material was used.

TABLE VI.

Composition of Material used :—All material RW.

TW.	TD.
♂s : ♀s=1 : 1	♂s : ♀s=1 : 1
3rd : 4th : 5th=1 : 1 : 1	3rd : 4th : 5th=1 : 1 : 1

Group	cm./min. range	TW.		TD	
		No.	Percentage	No.	Percentage
1	0– 5	20	64·5	17	54·8
2	5–10	3	9·7	7	22·6
3	10–15	5	16·1	5	16·1
4	15–20	1	3·2	1	3·2
5	20–25	1	3·2	1	3·2
6	25–30	1	3·2	0	0·0
7	30–35	0	0·0	0	0·0
Totals		31	99·9	31	99·9

These differences are small, and perhaps not significant. In so far as they are significant, we must conclude that humidity during the determination has an opposite effect upon instars 1 and 2 to its effect upon instars 3–5, all RW. In the first two instars a dry atmosphere has a depressing effect upon activity, while in the older hoppers it has a stimulating effect. The stimulating effect is not difficult to understand, since a dry atmosphere represents a change of conditions to insects RW., and most changes of conditions are stimulating. The depressing effect in the case of the first two instars may be connected with the fact that a very low humidity is evidently strongly unfavourable to hoppers in these stages, since they do not survive in such conditions for more than a few days. There were not sufficient records for instars 3–5 RD. to permit of separate analysis.

(2) *The effect of keeping the insects wet or dry during the whole developmental period (RW., RD.).*

In comparing RW. and RD. only instars 3–5 were used, since no figures for RD. were available for the first two instars. The composition of the material used is indicated at the head of Table VII. Almost equal numbers of the two sexes were used in each case, and the ratio between the numbers of the three instars was almost the same ; the ratio between TW. and TD. was higher in the case of RD (see below). Table VII shows that the percentage in group 1 is nearly 20 per cent. more for RD. than for RW., and in RD. there is only one record beyond the second group, *i.e.*, insects reared dry were definitely less active than insects reared wet.

TABLE VII.

Composition of Material used :—

RW.	RD.
♂s : ♀s = 35 : 33	♂s : ♀s = 18 : 17 (36 : 34)
3rd : 4th : 5th = 21 : 26 : 21	3rd : 4th : 5th = 11 : 13 : 11 (22 : 26 : 22)
TW : TD = 36 : 33	TW : TD = 27 : 17

Group	cm./min. range	RW.		RD	
		No.	Percentage	No.	Percentage
1	0–5	42	61·8	28	80·0
2	5–10	10	14·7	6	17·1
3	10–15	10	14·7	0	0·0
4	15–20	2	2·9	1	2·9
5	20–25	2	2·9	0	0·0
6	25–30	2	2·9	0	0·0
7	30–35	0	0·0	0	0·0
Totals		68	99·9	35	100·0

Thus the effect of introducing a number of RD. records into a series of RW. records would be to depress the average activity, *i.e.*, to raise the percentage in group 1. Now if we consider Tables IV and VI we see that the material used in Table IV is the same as that in Table VI, plus about a third RD. records, and, as would be expected, the percentages in group 1 have been raised. But it is to be noticed that almost all of the rise has taken place among the TD. records, the TW. records being hardly affected. This may be explained by making the simple assumption that a wet atmosphere is stimulating to insects reared dry, just as a dry atmosphere is stimulating to insects reared wet. Thus the depression of activity which would be expected from the inclusion of one-third RD. records is almost offset in the case of TW. by this stimulating effect, while in the case of TD. it can make itself fully felt.

The reduced activity of insects reared dry is further confirmed by Table VIII, which is not so reliable as Table VII, since it does not take into account the relation between the numbers of TW. and TD. used. It shows an excess of RD. over RW. in group 1 of 23·6 per cent. in the males and 8 per cent. in the females. Table IX, which contains all the available records, divided into RW. and RD. without selecting exactly equal numbers of the two sexes, etc., entirely supports the figures in Table VII, and has the advantage of containing 50 per cent. more records. The values given in this table are plotted in fig. 6.

TABLE VIII.

Composition of Material used :—

	♂♂		♀♀	
Instar	RW.	RD.	RW.	RD.
3rd	7	4	6	5
4th	7	4	6	5
5th	7	4	6	5

		♂♂				♀♀			
		RW.		RD.		RW.		RD.	
Group	cm./min. range	No.	Percent.	No.	Percent.	No.	Percent.	No.	Percent.
1	0– 5	11	52·4	9	75·0	13	72·2	12	80·0
2	5–10	3	14·3	2	16·7	3	16·7	3	20·0
3	10–15	5	23·8	0	0·0	1	5·6	0	0·0
4	15–20	1	4·8	1	8·3	0	0·0	0	0·0
5	20–25	1	4·8	0	0·0	1	5·6	0	0·0
6	25–30	0	0·0	0	0·0	0	0·0	0	0·0
7	30–35	0	0·0	0	0·0	0	0·0	0	0·0
Totals ...	...	21	100·1	12	100·0	18	100·1	15	100·0

TABLE IX.

All available Records classified into RW. and RD.

		RW.		RD.	
Group	cm./min. range	No.	Percent.	No.	Percent.
1	0– 5	72	64·3	42	82·3
2	5–10	16	14·3	7	13·7
3	10–15	15	13·4	0	0·0
4	15–20	4	3·6	1	2·0
5	20–25	3	2·7	0	0·0
6	25–30	2	1·8	0	0·0
7	30–35	0	0·0	1	2·0
Totals ...	...	112	100·1	51	100·0

Shelford, working on various animals, including insects, found that low relative humidity had first a stimulating and then a depressing effect upon activity. Rudolphs found that in mosquitoes there was an optimum humidity of about 94 per cent. when activity was highest, but his method of measuring activity was so different from that employed in the present work that no comparison of the results is possible.

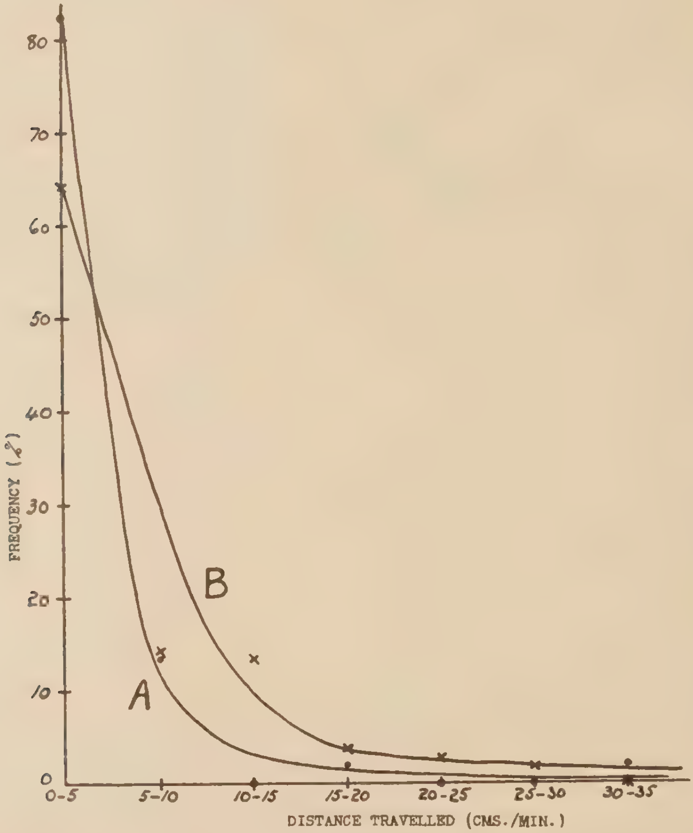


Fig. 6. Distribution of activity of (A) hoppers reared at very low humidity (ca. 10 per cent.) during development, and (B) of hoppers reared at saturation (Table IX).

(3) *Summary of the effect of relative humidity.*

Summarising the results of the above analysis of the effect of humidity upon activity, it can be stated that :—

1. A low humidity during development results, in instars 3–5, in relatively low activity as compared with a very high humidity. Intermediate humidities were not employed. This lowering of activity may be due to the fact that insects reared under these very dry conditions grow extremely slowly (Key, 1936a) and have been found upon dissection to be emaciated and poorly developed. The conditions are very extreme and survival is only just possible under them. First and second instar nymphs cannot survive.

2. In the case of instars 3–5, insects reared dry seemed to show a heightened activity when placed in a wet atmosphere, and insects reared wet to show a heightened

activity when placed in a dry atmosphere. These results, if significant, may be interpreted as being due to the stimulation resulting from change of environment.

3. In the case of instars 1 and 2, the opposite effect was noticed : insects reared wet showed a reduced activity in a dry atmosphere.

Difference in Activity between the Sexes.

In Tables VIII and X records are classified according to the sex of the insects used. Only 3rd–5th instar hoppers are considered : in earlier instars the sex differences are so slight as to be probably without effect upon activity. No adults are included, since very few determinations were taken of adults (see p. 400). The tables agree in showing a higher degree of activity of males than of females. Among insects reared wet the difference (Table VIII) amounts to 19·8 per cent. in group 1 ; among insects reared dry it amounts to 5 per cent. I do not insist upon the significance of the difference between these two figures, 19·8 and 5·0, since the number of records is small, especially among the RD. ; it is not inconceivable, however, that the effect of a dry atmosphere during development might be greater in the males, whose activity under normal conditions is relatively high, than in the females, whose activity is normally relatively low. In Table X, in which RW. and RD. are in the ratio of 3 : 2, the difference between the sexes is just 10 per cent.

TABLE X.

Composition of Material :—Equal numbers of instars 3–5.

RW : RD=3 : 2

Group	cm./min. range	Males		Females	
		No.	Percent.	No.	Percent.
1	0–5	20	66·7	23	76·7
2	5–10	4	13·3	5	16·7
3	10–15	4	13·3	1	3·3
4	15–20	1	3·3	0	0·0
5	20–25	1	3·3	1	3·3
6	25–30	0	0·0	0	0·0
7	30–35	0	0·0	0	0·0
Totals	... ...	30	99·9	30	100·0

Differences in activity between the sexes is apparently normal in animals. Richter and others have found that in rats the female is more active than the male, while Meunier finds that in *Melolontha* the male is more active than the female, the difference varying from 10 per cent. to 50 per cent., according to the stage of development of the beetle. This percentage difference is, of course, not necessarily comparable with the difference in the percentages in group 1, which are shown in Tables VIII and X. Bodenheimer found that in *Schistocerca gregaria*, Forsk., oxygen consumption in the male was about 40 per cent. higher than in the female, and Everly, working on *Melanoplus*, showed that the number of jumps per hour was much greater in the male.

Stage of Development and Activity.

Table XI shows the distribution curves separately calculated for each instar. In each instar equal numbers of the sexes, of TW. and TD., were used, and RW. : RD. was 2 : 1. In each instar both RW. and RD. were composed of equal numbers of TW. and TD.

TABLE XI.

Composition of Material :—

In instars 3–5 : equal nos. of males and females, of TW. and TD. ; RW. : RD.=2 : 1. In each instar (3–5), RW. was composed of equal nos. of TW. and TD., and the same was true of RD. 1st and 2nd instars all RW.

Group	cm./min. range	1st		2nd		3rd		4th		5th	
		No.	%	No.	%	No.	%	No.	%	No.	%
1	0– 5	14	70·0	15	65·2	15	83·3	19	63·3	12	66·7
2	5–10	4	20·0	2	8·7	0	0·0	5	16·7	3	16·7
3	10–15	2	10·0	3	13·0	2	11·1	3	10·0	1	5·6
4	15–20	0	0·0	2	8·7	0	0·0	1	3·3	2	11·1
5	20–25	0	0·0	1	4·4	1	5·6	1	3·3	0	0·0
6	25–30	0	0·0	0	0·0	0	0·0	1	3·3	0	0·0
7	30–35	0	0·0	0	0·0	0	0·0	0	0·0	0	0·0
Totals	...	20	100·0	23	100·0	18	100·0	30	99·9	18	100·1

The most striking feature of these figures is the great similarity of the distribution in the various instars, with the exception of the third, which is obviously in the nature of a freak distribution due to the small number of records. When we consider the very great difference in size between the first and fifth instars, it is, to say the least of it, surprising to find their activity so similar. True, there are no records beyond the third group in the first instar, but the fifth instar stops at group 4, and the second instar actually has a record in the fifth group.

Bodenheimer, in his studies on the rate of progression of hoppers of *Schistocerca gregaria*, made a similar observation. He found that the maximum speed of progression, which was reached at about 30°C., was the same for all instars, and that hoppers of all instars took part in the mass movements, the small ones keeping up with the big ones without apparent difficulty. His work on the relation of various activity grades to temperature points to the same conclusion, though he does not expressly state this. When his figures for the temperatures which are sufficient to call forth the various activity grades in each instar are plotted, it is seen that the curves cross and re-cross, and give no indication of a real difference between the instars. This evidence is much less reliable, owing to the difficulty in homologising a given activity grade in different instars.

Now if it be accepted that the activity of the various instars as exhibited in the activity cages is the same for all instars, *i.e.*, that each instar travels the same distance under these conditions, then certain interesting conclusions can be drawn.

The progression of a hopper may be regarded as being made up of a number of steps of equal length. The length of a step of any instar will be proportional to the length of the leg. Bodenheimer has shown for *Schistocerca gregaria* that the length of the hind femur is proportional to the length of the body, the greatest difference between the instars in this proportion being 15 per cent. between the first and fifth. Thus we may consider the length of a step as proportional to the cube root of the insect's weight. Work by the present author on growth in *Locusta* has provided figures for the ratios between the cube roots of the average weights of the instars. These ratios are (first to fifth instars) : 1 : 1·3 : 1·8 : 2·4 : 3·4. They should represent approximately the ratios between the lengths of the steps taken by the various instars. An attempt was made to determine experimentally the length of the steps taken, but this attempt was not successful.

Thus the fifth instar, using the above figures, takes steps 3·4 times as long as the first instar. This means that in travelling the same distance, say, 100 cm., the first instar takes 3·4 times as many steps as the fifth. Now the energy expended in taking one step is proportional to the weight of the limb and to the weight of the body. Bodenheimer has shown that in *Schistocerca* the ratio of the limb-weight to the body-weight does not vary among the instars by more than 15 per cent., so that we may say that the energy expended in taking one step is proportional simply to the body-weight. But the total amount of chemical energy available for locomotion must also be proportional to the body-weight, so that the amount of energy expended in taking one step must be proportional to the total amount of energy available for locomotion, must be some definite fraction of it.

Therefore, when the first instar travels the same distance as the fifth, and in so doing takes 3·4 times as many steps, the fraction of its total energy which it expends is 3·4 times as great as the fraction expended by the fifth instar. Therefore, since activity under the conditions used is entirely " spontaneous " we must conclude that the nervous system of the first instar functions more actively than that of the fifth, in so far as automatic nervous discharge is concerned. This conclusion applies, in different degree, to the other instars also. The older the hopper the less actively does the nervous system function as a centre of automatic nervous discharge. It cannot be too strongly emphasized that this conclusion applies only under certain special conditions. It is quite possible that under certain conditions of active stimulation the older hoppers may show an intensity of activity commensurate with their size. The impression was gained that although the early instars travelled as far as the later ones they did not travel as fast, but rather spent less time in inactivity.

Only five determinations were made of the activity of adults, so that no analysis is possible of its distribution, but the behaviour of adults reared under perfectly constant conditions, in isolation, and with plenty of food, appears superficially to be even more sluggish than that of the older hoppers.

Changes in activity in connection with ecdysis were not investigated. A more suitable method for such investigations would be the actograph. In the present work care was taken not to use for the purpose of the determinations insects which were approaching the moult.

Jumps.

Everly, working on *Melanoplus differentialis*, found that " spontaneous " jumping occurred when the insects were kept in a special recording cage in the absence of definite sharp stimuli. External factors were not constant, light intensity and temperature showing the normal daily changes, and the author found evidence for believing that the number of jumps per hour was influenced by light intensity. The insects were inactive all night, and their greatest activity was at dusk. This variation in activity was not due to temperature changes ; in continuous light the jumping was evenly distributed throughout the 24 hours.

In the experiments with *Locusta* jumping was extremely rare. In the course of over 200 determinations on both *solitaria* and *gregaria* hoppers of all stages, extending over more than 100 hours, only two undoubted jumps were recorded and four possible jumps. In the case of an insect jumping from the roof of the cage it was, of course, a matter of difficulty to be sure that the insect had not merely fallen down owing to having lost its foothold. In another apparatus, however, in which similar determinations (unpublished) were carried out at a light intensity of about 20 ft.-cands., seven of the 60 determinations yielded between them 18 jumps ; 15 of these, from four determinations (one determination had 10 jumps, and must be regarded as abnormal) referred to insects tested in the C.T. room at 27°C., the remainder to insects in an incubator at 40°C. Thus the temperature factor does not appear to be of importance, and it seems probable that the difference in the results obtained with different forms of apparatus is due to the different light intensities employed.

There was no indication that the jumps were confined to one or other stage, sex or set of conditions. Neither was the occurrence of jumps in either of the forms of apparatus connected with a high walking activity ; they occurred quite independently of the amount of ordinary activity. There is no question that the jumps recorded occurred quite spontaneously, *i.e.*, without definite external stimulus ; even in the case of the insect which gave ten jumps in half an hour, the administration of moderate shocks to the apparatus failed to evoke a single jump, though strong stimulation produces jumps under all conditions.

Discussion.

Broadly speaking, we may deduce from the results of various investigators that the activity of an organism is made up as follows : (1) There is a basic rhythm of spontaneous activity, which may be the result of an internal physiological rhythm, such as the hunger rhythm, or may be the result of an environmental rhythm in the previous experience of the organism (Richter, Szymanski, Wolf, etc.). (2) The level of this rhythm—*i.e.*, the absolute intensity of the activity, as distinct from its relative intensity at different times, may be affected by the level of certain constant internal or external conditions, such as inherent excitability and temperature respectively (Richter, Szymanski, Wolf, etc.). (3) A sudden change in certain external conditions acts as a stimulus which profoundly upsets the normal rhythm. The extent and form of the reaction to such a stimulus is again dependent upon the level of certain constant internal and external conditions, and upon the intensity of the stimulus (very many authors).

(1) The existence of a periodicity in spontaneous activity has been demonstrated for *Locusta*, but the nature of this rhythm and of the factors which cause it has not been given any attention and is quite unknown.

(2) The difference in the level of activity between insects reared wet and insects reared dry—a difference in previous environment—was considerable, while the effect of humidity differences in the immediate environment was very slight. Some incomplete experiments on the effect of temperature on spontaneous activity suggested surprisingly that even the temperature of the immediate environment had little effect on the spontaneous activity, in spite of its important influence on reflex activity. Experiments on *gregaria* hoppers in isolation, which are not included here owing to lack of proper control of all the conditions, suggested that these hoppers showed a higher degree of spontaneous activity than *solitaria*. Here again, the difference between *gregaria* and *solitaria* is due to a difference in previous environment.

I want to suggest that the greater activity of *gregaria* is just a special case of a wider relationship. It seems probable that the degree of excitability of an insect to stimuli, and the rate of its automatic nervous discharge in the absence of stimuli, depend upon the extent to which it was subjected to stimulation previously. That is, frequent excitation raises nervous tone, just as frequent exercise raises muscular tone. This is a long-period effect. The short-period effect of too frequent nervous excitation is nervous fatigue, just as the short-period effect of too frequent muscular exercise is muscular fatigue. It would be very interesting to test this theory by making activity determinations on insects which had been reared under alternating conditions nearer to those obtaining in the field, and comparing the results with those obtained under constant conditions.

(3) Though the present investigations have not been concerned with the effect of stimuli upon activity, it is obvious that any general discussion of activity must be very largely concerned with this aspect of the question. The fundamental difference between a crowd and an isolated individual only becomes apparent when we consider the effect of stimulation.

Stimuli have been classed as directive and non-directive. Perhaps more significant terms would be " determining " and " initiating." A determining stimulus is powerless to affect activity unless it has been initiated by automatic nervous discharge, or by an internal or external initiating stimulus. Determining stimuli are constant components of the environment, such as light, temperature and gravity. They may determine the direction, intensity and duration of a reaction, and they may lower the threshold for the effectiveness of the initiating stimulus, but they do not initiate the response. The essence of an initiating stimulus is that it constitutes a change in some external condition of sufficient suddenness to arouse activity. Thus a high constant temperature will not function as an initiating stimulus, though it may lower the threshold for other initiating stimuli, but a sudden change in temperature may constitute an initiating stimulus. When the initiating stimulus is of mild intensity, the form of the reaction is determined by the presence of any determining stimuli ; when it is of high intensity, the directive elements of the determining stimuli are often without effect (Szymanski).

Though activity can be initiated by internal stimuli or by automatic nervous discharge, it is probable that it is most usually initiated by some definite external stimulus. Once activity has been initiated, factors may be present to maintain it for a while. One such factor is the presence of an adequate determining stimulus. But even in the absence of adequate determining stimuli, there are other factors which tend, in an unfatigued animal, to induce continuance of activity for a time. These are the stimuli due to the movements of the limbs, etc., and to contact with the substratum. They are very slight, however, and activity soon ceases. Since the intensity of these secondary stimuli will be proportional to the initial reaction, which is proportional to the initiating stimulus, it follows that the more intense the initiating stimulus the more intense and prolonged will be the ensuing activity.

Where once the initiating stimulus has been intense enough to induce a jump, the secondary stimuli are the more intense owing to the violent impact with the ground after the jump. Thus a study of the stimuli adequate to jumping becomes important from the point of view of activity. There may be a very small quantitative difference between the intensity of a stimulus just sufficient to cause a jump and one just insufficient, but the difference in activity must be considerable. Temperature may have a very disproportionate effect upon activity under certain conditions by lowering the threshold of the stimulus required to induce jumping.

We may now proceed to consider the essential differences between a crowd and an isolated individual in relation to stimulation. In the case of an isolated hopper, each successive secondary stimulus, following upon an initiating stimulus, is less than the previous one, stimulation soon falls below the threshold value, and activity ceases long before fatigue sets in. The earlier instars appear to have a lower threshold. In the case of an active crowd, however, once activity has been initiated any given individual in the crowd is submitted to a bombardment of stimulation from all sides, and of several different kinds, the combined effect of which is probably very much *greater* than the initiating stimulus, and which probably evokes the maximum response of which the animal is capable. This intense stimulation can only be reduced as the insects fatigue, and the quiescent state which is ultimately reached is due partly to fatigue and partly to the diminution in stimulus resulting from fatigue, whether this fatigue is located in the receptors, in the nervous co-ordination, or in the muscular elements.

Further points about the induction of activity in crowds are : First, that activity of the whole crowd is controlled by the individuals with the highest irritability, *i.e.*, with the lowest threshold. The initiating stimulus is a trigger stimulus—a detonator which releases an infinitely more powerful stimulus. Secondly, in a crowd covering some considerable area, initiating stimuli of adequate intensity may exist at only one or two points, yet the activity released by them is transmitted to the whole crowd and affects individuals situated under conditions where, even in a small crowd, let alone in isolation, there would be no activity.

Thus all these various factors cause an individual member of a crowd to be submitted to stimulation immeasurably greater than an isolated hopper receives. The effect of this stimulating environment (see (2)) is to increase nervous excitability and reduce the threshold for response to stimuli, thus enabling still higher activity to be realised.

The deposition of black pigment in the cuticle, which is no doubt a result of this tremendous activity, is supposed (Uvarov and others) to enable a rise in body temperature to take place, which further increases activity. In my opinion this is an insignificant element in the situation. The rise in body temperature is at most 4° C. in black, as compared with pale hoppers (Bodenheimer, Hill & Taylor, Buxton). This will only have an appreciable effect on activity at the thresholds for activity. At the low threshold it will enable activity to begin at a temperature 4°C. lower than in pale individuals, but, equally, at the upper threshold, it will cause activity to cease at a temperature of 4° C. lower than in pale individuals.

The above considerations support the view, which is gaining ground at present, that both the morphological, and even most of the physiological, differences between the phases, extremely interesting though they are, are secondary to the subtle nervous difference which we call increased irritability. Obviously this nervous difference has a physiological basis, but we can only guess at its nature.

It cannot be held that the method of recording employed in this investigation is satisfactory in all respects. It is extremely laborious, and takes up a great deal of time in relation to the results obtained. At the time that it was devised all the difficulties in its application were not foreseen. For some of the work undertaken, the actograph, though less precise, would have been more useful. On the other hand, results can be achieved with the apparatus employed which no other method would yield.

Summary and Conclusions.

(1) A technique was devised for determining quantitatively the " spontaneous " locomotor activity of hoppers of *Locusta migratoria migratorioides* in terms of the distance travelled in half an hour in a special activity cage in which temperature, light intensity and humidity could be accurately controlled and all stimulation avoided.

(2) All the material used was derived from the same stock, and was kept under very constant and accurately known conditions from the time of hatching.

(3) The activity as measured in this way showed extremely great variation, as would be expected from our knowledge of the periodic character of " spontaneous " activity in many animals.

(4) Distribution curves were plotted showing the frequency with which various levels of activity were reached, and these curves were used as a basis for comparing the amount of activity shown under different conditions. In all these curves the mode was at the origin ; by far the greater portion of the activity was of a very low order, though high activity occurred occasionally. The hoppers showed about 70 per cent. of their activity in the lowest activity group (0–5 cm./min.). The percentage fell very rapidly to the next group (14 per cent.), and then gradually to the 30–35 cm./min. group (0·6 per cent.), beyond which the records did not go.

(5) Hoppers kept throughout development in a very dry atmosphere showed a lower activity than hoppers kept in a very moist atmosphere.

(6) Differences in the relative humidity of the atmosphere in the activity cage had very little effect on activity. The figures obtained suggested, but did not prove, the following :—

(*a*) First and second instar hoppers were more active in a wet than in a dry atmosphere.

(*b*) Hoppers of instars 3–5 showed the greater activity in the humidity which represented a change from that at which they had been kept during development : those reared dry showed greater activity in a moist atmosphere : those reared wet in a dry atmosphere.

(7) The figures suggested that males were more active than females.

(8) Broadly speaking, all the various instars travelled the same distance in the same time. A consideration of the facts relating to size in the various instars led to the conclusion that the younger instars must have a higher rate of automatic nervous discharge than the older instars.

(9) Jumps were hardly ever encountered at a light intensity of 3–4 ft.-cands., though quite a number were obtained at about 20 ft.-cands. These jumps were " spontaneous."

(10) The underlying causes of activity are discussed. It is concluded that external stimulation was by far the most potent factor in influencing the amount of activity exhibited, and that it was the crucial factor in the production of the gregarious phase, but that

(11) Previous environmental conditions, especially previous conditions of stimulation, modified both spontaneous and reflex activity by influencing the nervous excitability of the insect ; and

(12) Certain " determining " stimuli in the present environment affected the form, intensity and threshold of reflex, and, to a lesser extent, of spontaneous activity.

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References.

Bodenheimer, F. S., and others. (1930). Studien zur Epidemiologie, Oekologie und Physiologie der afrikanischen Wanderheuschrecken.—Z. angew. Ent. **15,** pp. 435–557, 55 figs.

BUXTON, P. A. (1924). Heat, moisture and animal life in deserts.—Proc. Roy. Soc. (B) **96,** pp. 123–131.

EVERLY, R. T. (1929). Preliminary experiments on the jumping reactions of *Melanoplus differentialis*, Uhler.—Ohio J. Sci. **29,** pp. 309–315.

FAURE, J. C. (1932). The phases of locusts in South Africa.—Bull. Ent. Res., **23,** pp. 293–405, 24 pls., 1 map.

HILL, L. & TAYLOR, H. J. (1933). Locusts in sunlight.—Nature, **132,** p. 276.

KEY, K. H. L. (1935). Experimental studies on locomotor activity in *Locusta migratoria migratorioides*, R. & F.—Thesis in library of University of London.

——, (1936). Observations on the rate of growth, colouration and the abnormal six-instar life cycle in *Locusta migratoria migratorioides*.—Bull. Ent. Res., **27,** pp. 77–85, 4 figs., 5 tables.

MEUNIER, K. (1928). Experimentelles über den Schwarmtrieb und das periodische Auftreten verschieden Aktivitätsformen beim Maikäfer (*Melolontha melolontha*, L.).—Z. angew, Ent., **14,** pp. 91–139.

RICHTER, C. P. (1927). Animal behaviour and internal drives.—Quart. Rev. Biol., **2,** pp. 307–343, 46 figs.

RUDOLPHS, W. (1925). Relation between temperature, humidity and activity of house mosquitoes.—J. N.Y. Ent. Soc., **33,** pp. 163–169.

SHELFORD, V. E. (1913). The reactions of certain animals to gradients of evaporating power of air. A study in experimental ecology.—Biol. Bull., **25,** pp. 79–120.

SZYMANSKI, J. S. (1920). Aktivität und Ruhe bei Tieren und Menschen.—Z. allg. Physiol., **18,** p. 105.

UVAROV, B. P. (1928). Locusts and grasshoppers.—Imp. Bur. Ent., London.

WOLF, E. (1930). Die Aktivität der japanischen Tanzmaus, und ihre rhythmische Verteilung.—Z. vergl. Physiol., **11,** pp. 321–344.

ON THE ROLE OF BLOOD IN OVULATION IN *AËDES AEGYPTI*, LINN.

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The intimate association between a blood meal and ovulation in all female mosquitos, with the exception of a few (de Buck, Roubaud) has been clearly recognised ; but the peculiar manner in which the presence of blood in the stomach can influence the formation of eggs is not understood. Two explanations may be suggested : it may either act as a physico-chemical stimulus to the ovarian follicles, or certain constituents in the blood may furnish some nutrient material for the development of the eggs.

MacGregor (1931) has made some interesting observations on the artificial feeding of mosquitos. According to him, while blood alone is capable of stimulating the follicles to develop eggs in *Aëdes aegypti*, it alone cannot do so in *Culex fatigans*.

We might perhaps understand the matter better if we could first determine whether this relationship is qualitative or quantitative. While a qualitative relationship would without doubt establish the hypothesis that the blood played the role of a stimulus, a quantitative relationship would suggest that some constituents of blood serve as material for the nourishment of the ovum. The purpose of this enquiry was, therefore, to determine the nature of this relationship between a blood meal and ovulation in *A. aegypti*.

The materials were bred from a culture which had been maintained in the London School of Hygiene and Tropical Medicine for a long time. The mosquitos employed for the experiments were mostly about three days old. They were allowed to feed on a human volunteer and the feeding in some was interrupted at various stages in the process, while others were allowed to feed to repletion. The eggs were laid on wet cotton-wool placed on a Petri dish inside a lamp globe. It was noticed that eggs were often found deposited on wet surfaces inside the chimney, especially near its lower rim. Several instances were noticed where the full complement of eggs was deposited in course of two days.

The results of the investigation are presented under the following headings :—

Weight of an unfed Female Mosquito.

It has been discovered that the weight of a mosquito undergoes considerable diminution in course of the first two days. Further, the weight taken immediately after it has emerged would be useless for the purpose of the investigation, for the reason that at this stage the mosquito is averse to feeding. Therefore three days' old mosquitos were chosen ; 1·32 mg. is the average weight of such a mosquito ; the maximum weight found was 2·32 mg. and the minimum weight 0·86 mg., out of a total of 137.

Weight of Blood Meal.

The amount of blood which a mosquito is capable of ingesting varies considerably in different specimens, but there is a general tendency for them to feed to repletion when the feeding is not interrupted. Two specimens were encountered of which the ventral surface of the abdomen on the second day after a full feed had ruptured ; a small hernial protrusion of clotted blood could be seen. An identical phenomenon was observed by Fülleborn (1908).

The mosquito was first lightly anaesthetised with chloroform, and then weighed on a torsion balance. When it had sufficiently recovered, it was fed on a human volunteer on the same day and soon after was weighed again.

The average weight of blood ingested by a mosquito when the feeding was not interrupted was 2·07 mg., the maximum and the minimum figures being 3·16 and 1·06 mg., respectively, as calculated from a total of 137.

Number of Eggs Laid.

The mosquitos were allowed to feed only once without interruption on a human volunteer and the number of eggs laid has been tabulated as follows. The insects were not anaesthetised in the following series of observations :—

TABLE I.

Number of eggs	under 20	21–30	31–40	41–50	51–60	61–70	71–80
Total no. of eggs	0	75	170	255	475	256	221
Number of females ...	0	3	5	6	9	4	3

The average number of eggs laid by a single mosquito was found to be 48·4, the maximum and the minimum being 76 and 24 respectively.

Number of Eggs in relation to the Weight of Blood.

In order to give a clear picture of this side of the enquiry the mosquitos have been grouped into different batches according to the amount of blood ingested, *e.g.*, from 0 to 0·5 mg., 0·5 to 1·0 mg., 1·0 to 1·5 mg., etc. The results are presented in the form of a chart and a table (fig. 1 and Table II).

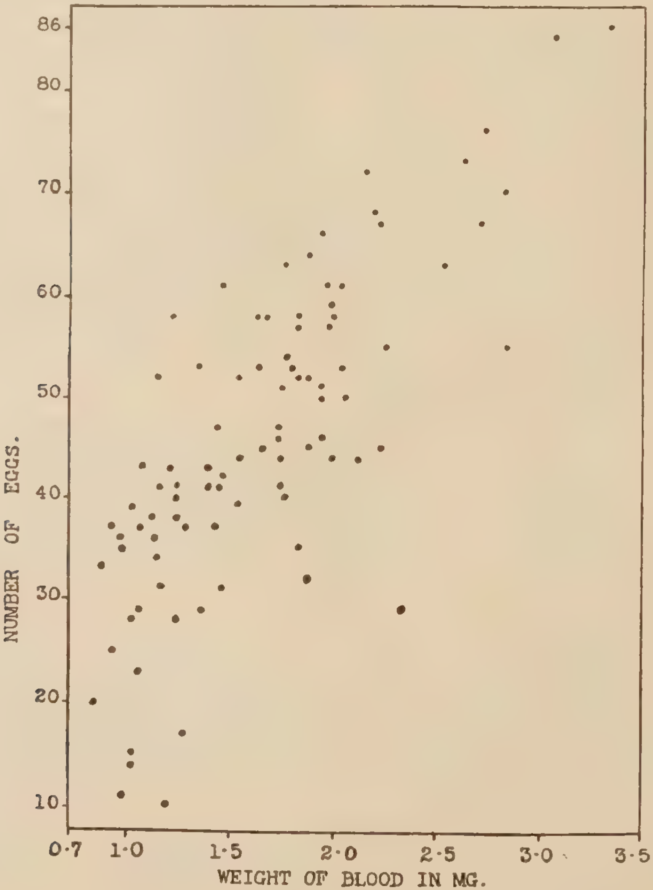

Fig. 1. Showing the relation of the number of eggs produced to the weight of blood meal for the first batch of eggs.

TABLE II.

Showing the Weight of Blood Meal and the Number of Eggs laid in the first Batch.

Weight of blood in mg.	0–0·5			0·5–1·0			1·0–1·5			1·5–2·0			2·0–2·5			2·5–3·0			3·0–3·5		
	Mean wt. of a mosquito	Mean wt. of blood	Mean number of eggs	Mean wt. of a mosquito	Mean wt. of blood	Mean number of eggs	Mean wt. of a mosquito	Mean wt. of blood	Mean number of eggs	Mean wt. of a mosquito	Mean wt. of blood	Mean number of eggs	Mean wt. of a mosquito	Mean wt. of blood	Mean number of eggs	Mean wt. of a mosquito	Mean wt. of blood	Mean number of eggs	Mean wt. of a mosquito	Mean wt. of blood	Mean number of eggs
	1·48	0·38	0	1·38	0·77	7·04	1·34	1·22	34·2	1·34	1·79	47·03	1·24	2·17	49·45	1·03	2·72	67·33	1·46	3·2	85·5
Total number of observations	21			28			35			34			11			6			2		
Total number of eggs laid ...	0			197			1,197			1,699			544			404			171		
Number of times when no eggs were laid ...	21			21			2			1			1			0			0		

It is evident from what has been shown that when the weight of ingested blood is less than 0·5 mg. no eggs are produced ; between 0·5 and 1 mg. eggs are only occasionally produced ; but a study of the figures in detail shows that the lower limit of blood which produces eggs was found to be about 0·8 mg., and to show this more precisely the mosquitos have been grouped as follows :—

TABLE III.

Weight of blood in mg.	0·5–0·6	0·6–0·7	0·7–0·8	0·8–0·9	0·9–1·0
Number of females	4	8	1	7	8
Total no. of eggs	0	0	0	53	144
No. of females which laid eggs ...	0	0	0	2	5
No. which did not lay eggs	4	8	1	5	3
Maximum no. of eggs	—	—	—	33	37
Minimum no. of eggs	—	—	—	20	11

The results clearly point to the fact that a minimum amount of blood is necessary for a mosquito to lay eggs, and 0·82 was found to be the lowest limit which will have an appreciable effect on the ovarian follicles.

The figures in Table II show that the mean number of eggs laid by a single mosquito progressively increases with the increase in the amount of blood feed. Thus with 0·5–1·0 mg. the mean number of eggs obtained was 7·04, which increased to 85·5 when the weight of blood meal was from 3·0–3·5 mg.

In the following table the mosquitos have been arranged in different batches according to the weight of blood taken, and the number of eggs corresponding to 1 mg. of blood has been calculated.

TABLE IV.

Weight of blood ...	0·5–1·0	1·0–1·5	1·5–2·0	2·0–2·5	2·5–3·0	3·0–3·5
Total no. of mosquitos which laid eggs	7	33	33	10	6	2
Total weight of blood feed	21·54	42·65	61·17	23·95	16·31	6·40
Total no. of eggs ...	197	1,197	1,699	544	404	171
No. of eggs per 1 mg. of blood	9·14	28·06	27·77	22·71	24·77	26·72

Although no definite correlation can be established from the figures cited above as regards an increase in the number of eggs with progressive increase in the amount of blood feed, yet it can be said that a small amount of blood has a tendency to produce a smaller number of eggs.

In order to determine the effect of several small interrupted feeds on the ovulation of mosquitos, five mosquitos were experimented upon ; they were allowed to ingest only a small amount of blood each time and the results have been tabulated below. It shows that while a small amount of blood in successive feeds had no effect on the mosquito, they were capable of producing eggs when the weight of blood meal at the third feed exceeded 0·5 mg., although the number of eggs was as a rule small.

TABLE V.

Wt. of unfed mosquitos	Wt. of blood first feed	Wt. of blood second feed	Wt. of blood third feed	Result
1·25	27 Nov. 0·65	29 Nov. 0·22	3 Dec. 0·88	no eggs
1·14	,, 0·38	,, 0·17	,, 0·59	9 eggs
1·44	,, 0·18	,, 0·26	,, 0·17	no egg
1·21	,, 0·16	,, 0·23	,, 0·64	11 eggs
1·60	,, 0·04	,, 0·15	,, 0·07	no egg

It has been stated previously that the minimum weight of blood at a single meal which can successfully induce a mosquito to lay eggs was found to be about 0·8 to 1·0 mg., and hence in the above observations it was assumed that no useful purpose would be served by feeding the mosquitos at sufficiently longer intervals.

Second batch of Eggs.

If 0·8 mg. represents the minimum weight of blood essential for the first batch of eggs, would the same amount be necessary before the mosquitos can successfully produce a second batch ? In order to determine this point, the mosquitos were given interrupted feeding soon after the first batch of eggs was laid. The results have been summarised in the following table. Out of a total of 18 observations, 11 mosquitos were given feeds varying from 0·13 to 0·45 mg., and no egg was laid. On the other hand, 7 females had opportunities to feed from 0·47 to 2·8 mg. of blood, and in every instance eggs were produced as shown below.

TABLE VI.

Wt. of blood	No. of eggs
0·47	15
0·78	31
0·81	34
0·84	34
1·27	40
1·95	58
2·80	71

It will thus be seen that while 0·45 mg. of blood was totally ineffective, the minimum weight of blood that had an appreciable effect on the ovaries after the first batch of eggs was produced was found to be 0·47 mg.

A study of the lowest weight of blood which can successfully stimulate the ovarian follicles to develop first and second batches of eggs showed that for the first batch this limit is 0·82 mg., while for the second batch it is at a considerably lower level, somewhere about 0·5 mg. This leads one to speculate as to what happens to this amount of blood, which is totally ineffective to stimulate the ovaries, and no eggs can be produced. It will certainly not be a correct interpretation to account for the loss of this blood in the body, if we state that this is consumed by the insect to enable it to perform its physiological functions and undergoes the same fate as proteins in higher animals. This fact has not been borne out from the study of the biology of mosquitos. Blood is only required for the insects to develop eggs. It seems that this material is in some way intimately connected with the functions of the ovaries.

It can be suggested that this amount, *i.e.*, 0·8 mg. for the first batch of eggs and 0·47 for the second batch, is required to stimulate the activity of the ovarian follicles themselves and that any amount in excess of this goes to form the eggs.

Weight of a Mosquito in relation to the Number of Eggs.

The relation of the weight and size of a mosquito to the number of eggs was also investigated, and the results have been summarised below in Table VII. For this, only those mosquitos which had not been disturbed in the process of feeding and which were allowed to suck blood till they themselves stopped feeding have been selected. The amount of blood meal has not been taken into consideration. Although it may be natural to suppose that the fertility of a mosquito depends on its weight, yet the results of the investigation do not lend support to that view. The mosquitos have been grouped in batches according to varying weights and the number of eggs has been shown against them. Thus it can be stated that the determining factor in the numerical productivity of eggs is by no means the weight of the mosquito but probably depends entirely on the amount of blood feed.

TABLE VII.

Wt. of mosquito, unfed ...	Below 1 mg.	1–1·5	1·5–2	2–2·5
Mean wt. of mosquito ...	0·85	1·35	1·82	2·17
Mean no. of eggs	42	44	57	36
Total no. of females ...	3	16	6	2

Conclusion.

The foregoing observations amply bear out the fact that there exists a definite quantitative relationship between the weight of blood meal and the number of eggs produced. Although theoretically this relationship should be on a graded quantitative scale, in practice this could not be confirmed. When the errors attendant on the determination of the exact weight of a mosquito in 1/100 parts of a mg. on a torsion balance are considered, a part of the anomaly can be easily understood, but there are other factors as well which have not been properly studied.

What portion of the different constituents of the blood is directly concerned with the formation of eggs is not known. When it is considered that 0·8 mg. of blood in the first batch and 0·45 mg. in the second batch is lost in the body, or in other words, that this amount plays no part in the formation of eggs, and that any amount, however small, in excess of this will cause the insect to develop eggs, it can be assumed that the protein elements in the blood after absorption exercise twofold functions on the ovaries. While one part acts directly on the follicles stimulating them to activity, the other part provides actual material for the formation of the eggs.

While assuming that two such factors exist, whether they are derived from the same protein element or from different fractions of the protein, no further light can at the present moment be thrown ; but from the behaviour of the ovaries it seems that the same element exercises dual functions.

The view that the number of eggs deposited by a mosquito varies directly with its size was not confirmed and it is likely that the amount of blood in its stomach exercises a greater influence than its own size.

I am grateful to Prof. P. A. Buxton for the courtesy he has shown in allowing me to work in his department in the London School of Hygiene and Tropical Medicine.

References.

DE BUCK, A. (1935). Z. angew. Ent., **22,** p. 242.
FÜLLEBORN, F. (1908). Arch. Schiffs. Trop. Hyg., **12,** p. 8.
MACGREGOR, M. E. (1931). Trans. Roy. Soc. Trop. Med. Hyg., **24,** p. 465. 19
ROUBAUD, E. & TOUMANOFF, C. (1930). Bull. Soc. Path. exot., **23,** p. 196.

ON A NEW SPECIES OF *NEMERITIS* BRED FROM THE BEE-HOLE BORER OF TEAK (HYM. ICHN).

By J. F. Perkins, B.Sc.,

Department of Entomology, British Museum.

Nemeritis tectonae, sp. n.

♀. *Head*: flagellum with 43 joints, the first joint distinctly longer than the second, the second just longer than the third; face punctate-reticulate, the punctures becoming sparser and finer towards the orbits; clypeus strongly, deeply and closely punctured; frons strongly and rather deeply punctured, the areas between the punctures, together with the vertex, strongly coriaceous. *Thorax*: parapsidal furrows rather deep anteriorly and extending to 1/3 the length of the mesonotum, which is strongly, deeply punctured (the punctures are a little closer to one another than the diameter of the punctures), with the general surface coriaceous and the disc rugose; sculpture of the scutellum similar to that of the lateral lobes of the mesonotum; mesopleura and mesosternum strongly, coarsely reticulate-punctate with the speculum smooth and shining, the area before the speculum coarsely, longitudinally striate; areolation of propodeum complete with the areola open behind, areola and petiolar areas strongly trans-striate, external areas shining and with shallow punctures, dentiparal areas transrugose, coxal areas finely rugose and the spiracular areas closely punctured; spiracles oval. *Legs*: hind coxae beneath with the sculpture similar to that of the external orbits; claws pectinate. *Abdomen*: petiole smooth and shining; postpetiole coriaceous but less strongly sculptured than segments 2, 3 and base of 4, which are very strongly minutely coriaceous; the apex of segment 4 and the remaining segments with the sculpture similar to, though weaker than, that of the petiole and somewhat shining; 6th and 7th segments with an apical dorsal excision; ovipositor sub-equal in length to the tibia plus 1st tarsal joint of the hind leg. Pubescence similar to that of *N. canescens*, Grav. *Wings*: fore wings with the areolet with a long petiole; hind wings with the transverse median vein broken just below the middle.

Colour: Black; scape and anellus (except for a dark dorsal longitudinal streak), mandibles (except the teeth), palpi, tegulae, front coxae beneath and the four hind coxae apically, all trochanters and trochantelli, yellow; all femora red; fore and middle tibiae and tarsi yellow with the tibiae marked with fuscous beneath and (narrowly) apically; hind tibiae outwardly pale testaceous in basal 2/3, internally testaceous and apically fuscous; abdomen with the 1st segment black, with a red apical spot, 2nd black in basal half and red apically, remaining segments red except for a small black basal spot on the 3rd.

♂. Differs from the female in having the costae and sculpture of the propodeum coarser and the areola closed posteriorly, the 3rd abdominal segment black basally and apically.

Length: ♀ 12 mm., ovipositor sheaths 4·5 mm.; ♂·11 mm.

Host: *Xyleutes ceramica*, Wlk. (Lepidoptera, Cossidae).

Type: ♀. Bred 29.viii.1934.

Allotype: ♂. Bred 22.ix.1935.

Burma: Chaungzon, Nanhlaing Reserve Forest (*D. J. Atkinson*).

Type and allotype deposited in the British Museum.

This species may be told at once from *N. palmaris*, Wilk., with which it is closely related, by the transverse median vein of the hind-wings being broken just below the middle, and by the sculpture of the mesopleura.

A Note on the Biology of Nemeritis tectonae, J. F. Perk.

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By D. J. Atkinson.

The Ichneumonid described in the preceding section is a primary parasite of the Cossid moth, *Xyleutes ceramica*, Wlk., the well-known Bee-hole Borer of teak (*Tectona grandis*). The existence of this parasite was known for some years before the insect itself was first taken, its empty cocoons having been found on rare occasions during the course of the writer's widespread analyses of bee-hole incidence throughout Burma. It was not until March 1934 that the parasite was found occurring with sufficient frequency to represent a controlling factor of any importance—in that month analysis of bee-hole conditions in a 1919 plantation in Nanhlaing Reserve, Mu Forest Division, revealed that parasitism by this insect had amounted to the surprising figure of 35·8 per cent. of all bee-holes found in the twenty-eight trees analysed. In no case, however, had parasitism been of that year, and all cocoons found were empty, the mouths of the parasitized bee-holes being occluded by at least two seasons' growth—it was not possible, therefore, to judge at what season of the year emergence of the adult parasite had taken place. The fact that all parasitized bee-holes were of the same size, 1½–2 inches long and the diameter of a slate pencil, equivalent to that of a normal unparasitized larva of about four months, seemed to imply one of two alternatives, either that death of the host larva had occurred during the rains, about August, followed by rapid pupation, transformation and emergence of the parasite (which would otherwise be trapped by the very rapid callus growth), or that parasitism had resulted in delayed development of the host larva, and consequently of the bee-hole, and that death of the host and emergence of the adult parasite had not taken place until the following hot weather. The latter alternative seemed at the time the more probable explanation, as implying synchronization of the life-histories of host and parasite, and obviating the necessity for the existence of an alternate host, which seemed obligatory if emergence of the parasite were to take place during August, when no larvae of the original host would be available for parasitism, it being apparent that only larvae of the very early instars were acceptable.

A visit was, however, paid to this forest during the following rains, in August, when no less than five living pupae of the parasite were taken after a few days' search (one cocoon being opened, to reveal a fairly advanced pupa, already showing signs of adult pigmentation). From these pupae only one adult emerged, on 29.viii.34, the female now described by Mr. Perkins, the remaining pupae unfortunately succumbing to mould. It is thus evident that of the two alternatives suggested above the former, thought at the time to be the less probable, is in fact the correct one, and that the existence of an alternate host seems absolutely necessary. The life-cycle of the primary host, *X. ceramica*, is annual, or in certain cases biennial, the adults emerging and ovipositing in the late hot weather (April–May in the locality concerned), the larvae appearing three weeks later, as the sap is rising. So far as present information goes the flight period of the moth is not prolonged, and does not exceed six weeks in any given locality (the life of individuals not exceeding a few days) ; there is consequently no great over-lap of early larval instars, and it is normally impossible that a parasite emerging in August should find more than a very few, if any, host larvae still in the early instars, and lying within the substance of the bark, within reach of the ovipositor. It seems imperative, therefore, that the period from August until the following May, when the next generation of host larvae will become available, must be passed by the parasite in some alternate host. So far, however, search for this alternate host has not been successful, though hope of obtaining it has by no means yet been abandoned. It seems probable that the alternate host will also be a larva living a concealed life, such as that of *X. ceramica*, though possibly Coleopterous rather than Lepidopterous, and it is apparent that a search for this insect may well occupy several years. This investigation is proceeding at present, and it is much to be hoped that it will result successfully, as to be in a position to increase parasitism from its normal 2 per cent. or 3 per cent. up to the 35 per cent. found to occur in the forest under reference might be of immense benefit to the many acres of existing teak plantations in which bee-hole incidence is at present severe.

EXPERIMENTS ON THE CROSSING OF OPEN SPACES BY *GLOSSINA SWYNNERTONI.*

By J. Y. Moggridge,

Tsetse Research Department, Tanganyika Territory.

Introduction.

Barrier-clearing, that is, cutting off from fly bush a tract of country which it is intended to render free from fly, is an integral part of tsetse reclamation measures, and " corridor " or road-clearing is a measure frequently employed to afford fly-free passage through tsetse-infested bush. The value of such clearings depends upon their effectiveness in confining tsetse to the bush the boundary of which is determined by the margin of the clearing.

Great variation in conditions, meteorological and physical, may be found in clearings and these may affect the value of the clearing as a barrier to tsetse. It may be that a clearing under one set of conditions may be broad enough to prevent the passage of tsetse across it, but under another set of conditions it may be found that passage is taking place and that tsetse are harbouring in the clearing itself.

The experiments were designed to show to what extent *G. swynnertoni* is capable of crossing an open space from fly-infested bush when carried on (1) game, (2) cattle and man, and (3) man alone. Later the experiments were continued to show the maximum time that *G. swynnertoni* could be carried on man and on cattle across an open space. Experiments were also undertaken to give information as to the distance at which a target moving in the open will attract tsetse to it from the bush.

Conditions of the Experiments.

At the south-eastern corner of the Huru-Huru " mbuga " (open low-lying grassland on black clay soil), approximately 12 miles west of Old Shinyanga in the Lake Province of Tanganyika Territory, there is a sharply defined line of junction between the red soil of Lohumbo with its vegetation of *Acacia*, *Commiphora* and *Combretum* and scanty grass growth and the black clay soil with its thick covering of coarse grasses and absence of bush. The line of junction is particularly clearly defined as a result of minor clearing operations which were undertaken in the area, the object of which was to " clean-up " the bush line at the junction of the two soil types.

To the north of the Lohumbo bush edge and approximately 2,225 yards from it, there is situated in the mbuga a small area of comparatively high ground known as Sayu, the slopes of which were, at the time of the experiments, covered with trees, the dominant species of which was *Acacia formicarum*. At the time when operations were conducted to clean-up the edge of the Lohumbo bush, the fringe of *A. formicarum* along the south side of Sayu was also reduced to a uniform line.

As a result of these operations a certain amount of thorny trash was, at the commencement of the experiments, still in evidence at the two points where felling had been undertaken. Along the edge of the Lohumbo bush and for a depth of about 400 yards from it the felling of fairly dense *A. formicarum* had been done. The remains of the trees formed a clearly defined line of trash of an average height of about 3 feet. Scattered thinly about the fallen tree-trunks and branches a number of dead *A. formicarum* trees remained standing. Along the south edge of Sayu also the litter of fallen trees still remained. Viewed from the respective bush edge the adjacent trash showed as a dark confused line. At a distance of 650 yards from the south edge of the Sayu bush there remained one tree standing. Owing to the scanty rains the grass failed to attain a height of more than 15 inches and consequently had little effect in hiding from view the fallen trash.

The Lohumbo bush supports a dense population of *G. swynnertoni*, and in the trash of fallen trees on the edge of the bush it was found that a small number of hungry flies were usually to be encountered. In the woodland on the slopes of Sayu a small, and probably transient, population of *G. swynnertoni* was present.

Experiments were carried out for considerable periods in both the dry and the wet seasons : during the wet season from the latter end of February to the early part of May 1934 ; during the dry season from the middle of August to the latter part of September 1934.

Owing to the fact that the site of the experiments was somewhat remote little variation could be made in the time at which the experiments were conducted. The majority were done in the forenoon and early afternoon.

Every effort was made to keep the numbers of both men and cattle conducting the experiments as constant as possible. In the earlier experiments four and sometimes five oxen were used, but in the majority of experiments three only were used, and always the same three, which were of uniform size and white, black and red in colour. The number of natives assisting was almost invariably four. All experiments were supervised by the writer except those cattle-crossing experiments that were made during the period 3.iv.34–16.v.34, which were supervised by Native Assistant Mzee, who had assisted the writer in all his previous experiments and was thoroughly conversant with the method of conducting the experiments and with the recording of the results.

Wet Season Crossing Experiments with Cattle only.

In view of the known presence of fly at Sayu (at which place the cattle used in the experiments were kept) and in the acacia trash on the Lohumbo bush edge, the party leaving Sayu for the purpose of conducting the experiments were at pains to catch and kill any fly following from Sayu and later, when approaching the trash on the Lohumbo edge, fly attacking the party were captured and killed. Since the object of the experiments was to ascertain whether fly would follow or remain with cattle crossing the mbuga from Lohumbo to Sayu and in what numbers, the need for clearing the trash of roaming fly will be apparent. The fly clearing operations were done very thoroughly indeed ; on one occasion only was the operation conducted for so short a time as 45 minutes and frequently it was continued for 180 minutes.

Having cleared the trash of fly the cattle were then conducted to the bush proper and grazed there for a period and finally led to the margin of the bush where a count (often, owing to the activity of the fly and to the restlessness of the cattle, an estimate only) of the fly on and around the cattle was made.

In the early stages of the experiments difficulty was encountered in making the cattle cross the mbuga to Sayu without the encouragement, and therefore the proximity, of man. Fortunately the oxen selected had long been associated with each other and had formed part of a team accustomed to following roads and paths. It was the making of a narrow path, in every way resembling a game path, that contributed more than anything else to the highly successful crossings which were latterly achieved. The slightly winding course of the path, the occasional halt and the leisurely walk of the cattle contributed to an effect very closely resembling, both in manner and in time taken, a crossing witnessed by the writer of the same section of the mbuga by a herd of eland.

The count, or estimation, of the number of flies on or near the cattle having been completed, the animals were encouraged to pursue the path across the mbuga to Sayu. At a distance of at least 200 yards from the oxen the party followed and by

TABLE I.

Cattle Crossing Experiments.

Date 1934	Time in trash in mins.		No. of fly captured in trash		No. of fly on cattle before crossing	No. of fly on cattle on arrival at Sayu	Time taken in crossing in mins.	Remarks
			♂	♀				
6.ii	—	—	—	—	Very many fly	Nil	40	Oxen lay down and had to be encouraged by voice; 5 oxen
13.iii	12·55– 1·40	45	—	1	12	Nil	37	Fairly successful crossing; 5 oxen
19.iii	10·05–11·03	58	1	1	Very many fly	8	28	Unsatisfactory crossing; 5 oxen
27.iii	9·00–11·00	120	5	8	,, ,,	13	60	One ox lay down 4 times; 3 oxen
30.iii	9·00· 11·00	120	2	9	,, ,,	6	30	One ox dropped from experiment, others walked straight across; 3 oxen
3.iv.	9·00–11·00	120	5	9	Very many fly	8	30	Oxen went well without being approached; 3 oxen
9.iv.	10·00–12·00	120	3	6	,, ,,	8	30	,, ,, ,, ,,
13.iv.	10·00–11·30	90	4	6	,, ,,	6	30	,, ,, ,, ,,
16.iv.	10·00– 1·00	180	6	5	Few flies only	7	30	,, ,, ,, ,,
19.iv.	10·00–12·00	120	6	4	Very many fly	6	30	,, ,, ,, ,,
20.iv.	10·00– 1·00	180	4	7	—	5	30	,, ,, ,, ,,
22.iv.	9·00–12·00	180	2	4	Very many	6	30	,, ,, ,, ,,
26.iv.	10·00–11·00	60	4	8	,, ,,	7	30	,, ,, ,, ,,
2.v.	10·00–12·00	120	4	3	,, ,,	6	30	,, ,, ,, ,,
4.v.	10·00–11·30	90	2	3	Few only	6	30	,, ,, ,, ,,
7.v.	10·00–12·00	120	2	3	Very many	9	30	,, ,, ,, ,,
8.v.	9·00–12·00	180	4	6	,, ,,	8	30	,, ,, ,, ,,
10.v.	9·00–11·00	120	4	8	,, ,,	8	30	,, ,, ,, ,,
12.v.	10·00–11·30	90	4	3	,, ,,	10	30	,, ,, ,, ,, 4 oxen
14.v.	9·00–11·00	120	4	2	,, ,,	8	30	,, ,, ,, ,, 3 oxen
16.v.	10·00–12·00	120	2	1	,, ,,	8	30	,, ,, ,, ,, 3 oxen

frequent catches and examinations for flies ensured that no tsetse were accompanying them across the mbuga to complicate the final count of those flies still remaining on the cattle at the other side. In order to avoid the possibility of flies issuing from Sayu at the approach of the cattle and being included in the count the oxen were stopped at the single tree in the mbuga already mentioned as standing some 650 yards from the Sayu edge, and 1,575 yards from the Lohumbo edge.

Flies which were still remaining with the cattle at the time the tree was reached were captured and recorded.

Results.

Details of the crossings, some of the earlier ones of which were unsuccessful, are shown in Table I.

From 3rd April to 16th May, 16 successful crossings were made by three oxen (on one occasion four oxen took part), all of which took 30 minutes from the time of departure from the Lohumbo bush edge to the single tree standing 650 yards from the Sayu acacias. The average number of flies carried across was 8·5, and the actual numbers showed remarkably little variation. It is interesting to note that on the single occasion when four oxen made the crossing, the maximum number of flies were carried across. It will be recalled that the passage across the " mbuga " was 1,575 yards.

Dry Season Maximum Time Experiments with Cattle only.

During the dry season of 1934 experiments were undertaken with rather a different object in view from that of the wet season series. The latter were designed to show whether tsetse could be carried across an open space over 1,500 yards wide on game (cattle), cattle and man, and man alone. The dry season experiments were undertaken to throw light on the maximum time, and consequently distance, that tsetse could be carried across an open space through the agency of game, cattle and man, and man alone.

In order to ascertain the maximum time that *G. swynnertoni* would remain with cattle it was necessary to approach the animals frequently and to record the number remaining from time to time. Thus any attempt to imitate a game movement from one point to another had to be abandoned. The method used in these experiments was to drive the oxen through fly bush for a while and then out into the open for a distance of about 400 yards, at which point a count of flies was taken or an approximation arrived at. The oxen were then urged forward by word of mouth and the party sat down in the longest grass near at hand and prepared to catch such flies as had remained with them—actually only one fly was taken in this manner. After a few minutes the oxen were followed and stopped and a count made of the flies still remaining with them.

The same oxen as were used in the wet season series of experiments were used in this series, and three men—the writer and two Native Assistants—took part.

At the time these experiments were being conducted considerable areas of the mbuga had been patchily burnt and the ground over which the experiments took place was representative of the conditions prevailing over the greater part of the area.

Results.

Table II gives the time of the start and finish of each experiment and the number, or an estimation of the number, of flies on the cattle when they left the bush edge. The maximum time that a fly remained on an ox is also given.

The first experiment was conducted under different conditions from the other six. During the first experiment the sun was at first obscured and clouds covered four-fifths of the sky, later clearing to half the sky. To the north conditions were cloudy and stormy. The remainder of the experiments were conducted under a cloudless sky, moderate temperatures and in a moderate to high wind.

Flies which accompanied the cattle from the bush appeared to be very hungry, for they quickly became gorged and fell off.

Progress made from the bush edge by the oxen was very slow, probably about half a mile an hour.

Fig. 4 shows the rapid drop in numbers of flies accompanying the oxen and shows that in this series of experiments no flies remained with the cattle longer than for half an hour or for a distance greater than about 440 yards.

TABLE II.

Dry Season Maximum Time Experiments with Cattle alone.

Date	Time	No. of fly on oxen at start	Maximum time fly on oxen	Remarks
4.ix.34	10.38 a.m.–12.05 p.m.	Very numerous	1 hr. 27 mins.	Sun faint-bright
11.ix.34	10.35 a.m.–10.45 a.m.	Approx. 5 flies	10 mins.	Sun bright
11.ix.34	11.00 a.m.–11.15 a.m.	Few flies	15 ,,	,,
11.ix.34	11.30 a.m.–11.48 a.m.	Approx. 10 flies	18 ,,	,,
13.ix.34	8.50 a.m.– 9.13 a.m.	,, 5 ,,	23 ,,	,,
13.ix.34	9.23 a.m.– 9.37 a.m.	,, 5 ,,	14 ,,	,,
13.ix.34	9.51 a.m.–10.16 a.m.	,, 5 ,,	25 ,,	,,

Comparison of the Wet and Dry Season Results.

Comparison of the results of these two series of experiments can leave little doubt that game, as represented by oxen, are liable to carry fly for a longer time across an open space during the wet season than in the dry season. Apart from the climatic differences of the two seasons and the influence this may have on the fly while being carried across an open space, two other factors seem to have considerable bearing on the results obtained. The first and probably the more important is that during the wet season *G. swynnertoni* appears to be less in need of blood than it is during the dry season and consequently is less inclined to probe immediately on meeting its host. During the dry season the flies seemed particularly anxious to obtain a meal as soon as possible, and observations showed that the majority of the flies dropped off from the oxen in a gorged condition very soon after the animals had left the bush edge. The second condition noted to be different during the two series of experiments is that during the wet season very many more flies accompanied the cattle from the bush edge than were noted during the dry season series.

Wet Season Crossing Experiments with Cattle and Man.

The wet season series of this set of experiments was undertaken from 25.i.34 to 3.ii.34, and the site of the experiments was exactly that chosen for the first set, when cattle crossed alone.

The distance separating the Lohumbo bush line from the tree marking the end of the crossing was roughly divided into four parts, and at each point during an experiment a count was taken of flies on both man and cattle. The procedure prior to the crossing was the same as was observed in the previous cattle crossing experiments, with the exception that after the cattle had been grazed for a while in the Lohumbo fly bush they were driven slowly towards Sayu accompanied closely by the writer and his Native Assistants. It was the practice not to interfere with fly on the party unless forced to do so by the pain or annoyance caused by probing. The count of flies on man and cattle during the crossing was done without interfering with the flies in any way.

Results.

The results of these crossing experiments are shown in Table III. It will be noticed that fewer flies were carried across the mbuga in these experiments than was the case when the cattle made the crossing alone. In the first of the cattle and man series a total of ten flies was carried across, and this figure compared favourably with the totals recorded for the crossings by the cattle alone. It will be seen that in the man and cattle series, in spite of the larger target presented to the flies in the bush, few flies only, with the exception of the first experiment, accompanied the party from the bush edge. The time taken by the combined cattle and man party to cross the mbuga is slightly greater than that taken by the cattle alone, but the difference is too small to account for the discrepancy in the number of flies carried across. The discrepancy must be attributed to the fact that fewer flies attacked the party in the bush and followed out into the open.

The results which are shown in Table III are graphed on averages in fig. 2. The rapid fall in flies accompanying the oxen compared with the more gradual fall in the number of flies accompanying the men is instructive, and is reflected throughout the whole series of experiments. The rise in fly numbers shown at 320 yards and at the end of the crossing is due to flies which were not noticed in previous counts (owing probably to the fact that they were resting on the grass) being included in the later counts.

Dry Season Maximum Time Experiments with Cattle and Man.

Only two experiments were done in this series. The method was the same as that described for the wet season series and the site of the experiments was the same. Both experiments were carried out in the forenoon.

Experiment No. 1.

At the bush edge very many flies were noticed on the cattle but only a few on the members of the party. Within a few yards of the bush edge after entering the mbuga it was noted that the majority of the flies had obtained their feed and had dropped off. Within 17 minutes of leaving the bush no flies were to be seen on the cattle, but two were seen to be resting on members of the party. This distribution was maintained for a further 13 minutes, when one fly was seen to leave the cap of one of the Native Assistants and to settle on one of the oxen. It quickly became gorged and fell off. Seven minutes later no flies remained on the party. The total time during which flies were carried either upon the cattle or upon man was 40 minutes.

Experiment No. 2.

This experiment closely resembled the first, in that the majority of the flies became gorged within the first few minutes of the crossing and dropped off. The period of the experiment was extended, as before, by the persistence of one fly. The total time during which flies were carried was 47 minutes. This experiment was unsatisfactory for the reason that the Native Assistants captured all the flies on themselves immediately after leaving the bush edge. The one fly that remained for 47 minutes was carried during that period by one of the oxen.

Little of any value can be drawn from these two experiments, except that a fly—presumably a replete fly—is capable of being carried on cattle for as long a period as 47 minutes.

TABLE III.

Crossing Experiments : Cattle and Man.

Date	Party	Time	Fly at start on		1st stop		Distance from bush	2nd stop		Distance	3rd stop	
			Oxen	Man	Oxen	Man		Oxen	Man		Oxen	Man
25.i.34	5 oxen, 4 men	10.45–11.20=35 m.	±40	±24	±40	±24	600 yds.	3	13	½ way	2	13
27.i.34	5 oxen, 4 men	12.00–12.42= 42 m.	±6	4	6	6	300 ,,	±5	4	⅓ way	±3	3
30.i.34	5 oxen, 4 men	12.35–1.10=35 m.	±5	4	0	5	250 ,,	0	2	⅓ way	0	0
3.ii34	5 oxen, 5 men	11.28–12.01=33 m.	0	5	4	3	250 ,,	1	6	⅓ way	3	4

Date	Distance	4th stop		Distance	Sayu		Total	Remarks : Weather, etc.
		Oxen	Man		Oxen	Man		
25.i34	⅔ way	1	5	—	1	9	10	Cool and sunny, S.E. wind—over 100 per cent. more fly caught on self as compared with natives
27.i.34	½ way	2	Nil	¾ way	0	0	0	Stormy and unsettled ; again remarks as above *re* fly
30.i.34	½ way	1	1	⅔ way	0	1	1	Sunny and fresh, fly not numerous in trash
3.i.34	½ way	1	2	⅔ way	0	1	1	Sunny and fresh

Wet Season Crossing Experiments with Man alone.

It was the practice in this series of experiments for the party to walk about in the Lohumbo bush for some time before starting to cross the mbuga to Sayu in order to attract flies to them. The crossing was made in single file at a slow walking pace. Flies were not interfered with unless pain or annoyance was caused by probing. The crossing was roughly divided into four sections and at each section a halt was made to count the flies remaining on the party.

It should be noted that at the time these experiments were being made the danger of flies collected at the bush edge being augmented by flies from the acacia trash was not realised. Scrutiny of the fly numbers recorded gives some indication that on two occasions at least the numbers of flies carried on the party from the bush edge were supplemented by flies from the trash. Assuming this to be the case, the distance from point to point of the crossing must be reduced by about 400 yards, making the distance travelled through fly-free mbuga about 1,175 yards.

Results.

The results are given in Table IV, which shows the results of the crossing without regard to possible influence from fly harbouring in the acacia trash.

The results of these wet season crossings are shown in a graph (fig. 1), the figures having been reduced to an average for the purpose of graphing. The fall in fly numbers is shown to be comparatively steady relative to the distance travelled and resembles the form of the graph showing the fall in numbers of fly carried by man to distance travelled in the crossings by cattle and man (fig. 2).

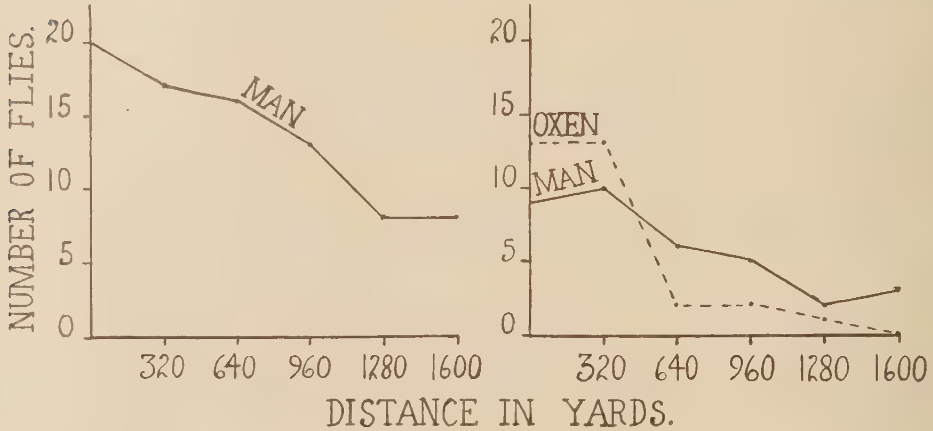

Fig. 1. Man alone. Fig. 2. Man and Cattle.
Averages for wet season 1934.

It is interesting to note that while the wet season series of crossings by man alone were being undertaken, on two occasions large parties of natives carrying bundles of cassava roots on their heads were examined at Sayu for flies after they had crossed the Huru-Huru mbuga from a point across the mbuga more than one hour's walk away from Sayu. The route followed by the natives across the mbuga was the same in both instances, and the time at which they were examined at Sayu was in each case 9.15 a.m. In the first instance a party of 120 men walking two and three abreast were examined. The weather at the time was dull, cloudy and cold. Nevertheless in spite of the early hour and unfavourable conditions the 120 men had carried across the open mbuga for a period of at least one hour 36 *G. swynnertoni*. In the second

TABLE IV.

Crossing Experiments : Man alone.

Date	Party	Time	Fly on party at start	1st stop No. of fly	Distance from bush	2nd stop No. of fly	Distance from bush
26.i.34	4 men	11.15–11.55=40 m.	35	40	300 yds.	31	500 yds.
29.i.34	5 ,,	12.40– 1.05=25 m.	4	1	350 ,,	4	⅓ way
31.i.34	5 ,,	11.05–11.30=25 m.	18	10	300 ,,	9	⅓ ,,
2.ii.34	4 ,,	11.47–12.18=31 m.	22	17	400 ,,	21	⅓ ,,

Date	3rd stop No. of fly	Distance	4th stop No. of fly	Distance	Sayu No. of fly	Remarks : Weather, etc.
26.i.34	34	⅓ way	13	⅔ way	15 {10 ♂♂ 5 ♀♀	Hot and sunny
29.i.34	3	½ ,,	3	⅔ way	3 ♂♂	Sun faint ; cloudy
31.i.34	4	½ ,,	7	—	8 {7♂♂ 1 ♀	Sun bright ; cool
2.ii.34	12	½ ,,	7	⅔ ,,	5 {4 ♂♂ 1 Y♀	Sun bright ; warm

instance under conditions of warm weather and bright sunshine a party of 57 men were found to be carrying 22 *G. swynnertoni*.

Dry Season Maximum Time Experiments with Man alone.

The place and the method followed were the same for this set of experiments as for the wet season crossing experiments, and all were conducted during the forenoon. The mbuga grass was patchily burnt at the time. The results are shown in Table V.

TABLE V.

Date	Time	No. of fly at bush edge	Max. time fly stayed with party
16.viii.34	11.30– 1.30	8	2 hours
17.viii.34	10.00–10.45	10	45 minutes
17.viii.34	11.10–11.17	2	17 ,,
21.viii.34	11.10–12.40	8	90 ,,
23.viii.34	10.30–11.20	8	50 ,,
23.viii.34	11.40–12.30	10	70 ,,
24.viii.34	10.38–11.35	8	57 ,,

All the experiments above were carried out under conditions of bright sunshine typical of the dry season. They have been graphed (fig. 3) and show a more gradual decrease in fly numbers relative to distance travelled than do the results of the experiments carried out in the wet season in which man took part (figs. 1, 2).

As was noted in the wet season series of experiments, the majority of flies become gorged in the early stages and a few flies, sometimes a single fly only, will remain with the party long after the others have left.

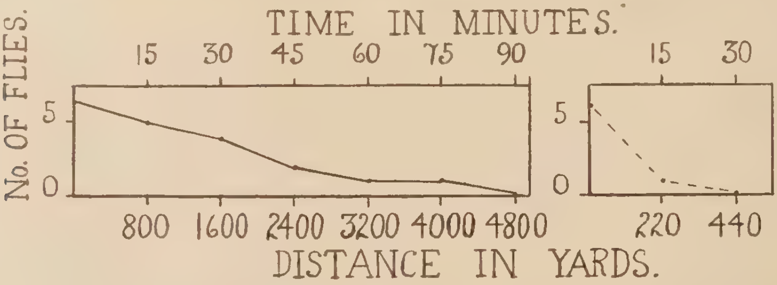

Fig. 3. Man alone. Fig. 4. Cattle alone.
Averages for maximum time experiments, dry season 1934.

It was noticed that in many instances the flies were carried on the caps of the Native Assistants and that they remained motionless in this position for long periods.

Summary of Crossing Experiments and Maximum Time Experiments.

(1) *G. swynnertoni* may be carried across an open space from fly bush a distance of 1,575 yards upon oxen (and therefore presumably on game) and upon man.

(2) The number of flies carried is in inverse ratio to the distance travelled.

(3) Relatively little difference can be noted between the number of flies carried by cattle and by man across the Sayu mbuga during the wet season series of experiments.

(4) The number of flies carried across the Sayu mbuga on either cattle or man is small in comparison with the number of flies attacking at the bush edge prior to the start of the crossing.

(5) The number of flies attracted to the bush edge prior to crossing appears to have an influence on the number of flies carried over, that is, the greater the density of flies in the bush the greater the number that will be carried across.

(6) The state of hunger of the flies attracted to the bush edge prior to starting would appear to have some influence on the number of flies carried across. The more hungry the flies are the less distance are they likely to be carried across the open before becoming gorged and dropping off.

(7) In the cattle and man series of experiments undertaken during the wet season, the average number of flies carried across the Sayu mbuga by man was greater than that carried across on the oxen. Fig. 2 shows that the flies are attracted to the cattle at the bush edge in greater numbers than they are attracted to man. The graph also shows that the flies leave the cattle rapidly, whereas the decrease in flies leaving the party is comparatively steady relative to distance travelled.

(8) A comparison between the wet season series of experiments and the "maximum time" experiments made during the dry season appears to indicate that fewer flies are attracted to the bush edge during the dry season than in the wet season, but it is realised that this is probably due to the fly population being less dense late in the dry season. The decrease in fly crossing on cattle during the dry season is considerably more rapid relative to the distance travelled than it is in the wet season. Figs. 1 and 3, dealing with the crossing of fly on man, show that although the numbers crossing during the wet season are less than those in the dry season, the decrease in fly numbers is gradual in both cases.

Experiments to find the Distance at which an Object moving in the Open will attract Tsetse from the Bush.

Information on the distance at which an object moving in the open will attract to it tsetse from the bush is particularly needed in order that corridor clearings may be made as economically as possible. Game are frequently to be found grazing in clearings, and the passage of flies on them across a clearing is believed to be a common occurrence. There can be little doubt that game grazing out of the fly bush into the open clearing take with them a number of flies. It is probable, however, that the majority of the flies carried out of the fly bush become gorged with blood and leave the animals before they have grazed their way across the clearing. There is the danger that fresh flies may be attracted out from the bush to the animals grazing in the open, and if this is so there is a greater probability of passage of flies across the clearing than would be the case if the animals ceased to be attractive to flies after they had left the habitat.

The margin of the Lohumbo bush and the Huru-Huru mbuga, close to the point at which the crossing experiments were commenced, was selected for these experiments. At the time they were undertaken the acacia trash, which was mentioned in connection with the crossing experiments, had been collected and burnt ; also the grass on the mbuga had reached maximum height and, owing to late rains, was still green.

Later in the year the experiments were continued about half a mile down the mbuga to the eastwards, where the vegetation differs somewhat from that higher up, and it was thought that in this type a higher percentage of hungry flies would be found which might influence the results. The vegetation of the second site is composed of *Acacia formicarum*, *Commiphora Schimperi*, *Lannea humilis*, *Combretum parvifolium* and *Justicia* sp. From the bush edge running out into the mbuga for some way there was low-growing and stunted *Harrisonia abyssinica*, *Dalbergia melanoxylon* and *Dichrostachys* sp. The grass in this area had, at the time of the experiments, been patchily burnt and resembled the conditions prevailing over the greater part of the Huru-Huru.

Below are tabulated the impressions gained of the visibility from the edge of the bush. In the first site :—

100 yards.	Oxen clearly visible above knees. Men clearly visible.
200 yards.	Upper sides and backs of oxen visible through grass. Men clearly visible from waist.
300 yards.	Backs of cattle visible. Men clearly visible above waist.
400 yards.	Upper line of backs of cattle visible through grass. Men visible above waist.

When viewed from a height of 3 feet from the ground, no movement of cattle or men could be observed at a distance from the bush edge greater than 200 yards.

In the second site the visibility was uninterrupted, except momentarily by tufts of unburnt grass, when movement was observed from a height of 3 feet from the ground.

The period of the experiments on the first site was from 4.vii.1934 to 13.vii.34, and that on the second site from 18.ix.34 to 20.ix.34.

Four Native Assistants and the writer and three oxen comprised the personnel in the first set of these experiments. In the second set the number of Native Assistants was reduced to three and three oxen were used.

The oxen used in the first set and in the first two experiments of the second set were trained and steady oxen, but owing to trypanosomiasis these oxen had to be rested, and the last three experiments were conducted with young and partly trained oxen. These young oxen were shy of the catching nets and became very restless when attacked by fly in any numbers.

First Set of Experiments.

Four transects, 345 yards long, were laid out at distances of 100, 200, 300 and 400 yards from the bush edge and parallel with it. The party of three oxen and four men patrolled each transect slowly once, starting from the 400 yards transect and closing the distance to the fly bush in order of successive transects. The party during the patrolling of the transects was led by one member and the oxen followed in single file, always maintaining the same order, while the rest of the party brought up the rear. During the patrolling of the transects keen watch was kept for flies attacking the party. When a fly was observed the party halted and the fly was captured and recorded. At the middle of each transect and at the end of it the party halted and a close examination was made of the oxen and men and also of the ground round about. At the start of each transect the time was noted, and a note was also made of the meteorological conditions.

Second Set of Experiments.

In these experiments three transects of 100 yards were laid out at 100, 200 and 300 yards distance from the bush edge respectively. In the majority of experiments the transects were patrolled four times. The procedure followed closely that described for the first set of experiments. In the second set it was customary to patrol the bush edge at the close of the experiments in order that an impression could be obtained of the fly density there.

During both sets of experiments the weather was typical of the conditions usually obtaining during the middle and late dry season. The sun was bright and clouds few to none, a moderate to fresh easterly wind was blowing up the transects slightly towards the bush edge. The conditions during one experiment in the first set were dull with three-quarters of the sky obscured by clouds. On that occasion no flies were captured on any of the transects and that was the only time that flies were not taken on the 100 yards transect.

Results of first Set of Experiments.

A total of 61 flies were captured during the first set of eight experiments. All the flies taken were caught on the 100 yards transect—no flies being taken on any of the transects more remote from the bush. The flies were taken as follows :—

Total number of males	37
Total number of females	24
	61
Captured off oxen	59
Captured off men	1
Captured off ground	1

The average time taken to patrol the 100 yards transect was 17 minutes.

The three oxen which were used in this set of experiments had previously worked together as part of a team. It is probably due to their training in the team that they always followed one of the Native Assistants along the transects in the same order, and during examination for fly they tended to stand together in the same order in a row. This latter tendency caused one ox always to stand on the bush side of the group, and it was thought that this might influence the number of flies captured off it as compared with the number captured off the other two oxen. Steps were taken to ensure that each ox in turn stood on the bush side of the group during the periodical examinations for flies.

A short description of the oxen is given below :—

Sultan—black, with a considerable amount of white on dewlap, belly and legs.
Liefland—yellowish red all over.
Transvaal—white.

The oxen were all of about the same size, and the order in which they followed the Native Assistant during the patrolling of the transects was (1) Sultan, (2) Liefland, (3) Transvaal.

An analysis of the number of flies caught off the oxen shows a great discrepancy between Liefland and the other two. The figures, shown as percentages of the total, are Sultan 45·76 per cent., Liefland 3·39 per cent., Transvaal 50·85 per cent.

No explanation can be suggested for the apparent aversion shown by the flies for Liefland. Mr. Swynnerton, in conversation with the writer, mentioned a very similar occurrence in his experience.

Results of second Set of Experiments.

Five experiments were done in this set. Three were done in the forenoon and two were done in the late afternoon. The total number of flies captured during the experiments was 17, made up of 4 males and 13 females.

Total number captured at 300 yards from the bush ...	1
Total number captured at 200 yards from the bush ...	4
Total number captured at 100 yards from the bush ...	12

With the exception of one fly, all the captures were made off the oxen. During the three forenoon experiments only three flies were captured (one fly at 300 yards and two at 100 yards) but during the two late afternoon catches 14 flies were taken (four at 200 yards and ten at 100 yards).

The trained oxen were used only twice in this set of experiments, once during the forenoon and once during the afternoon. These two experiments are the only ones of value as regards the number of flies captured off the oxen along the bush edge, for the young and partially trained oxen used in the other experiments of this set would not stand still when attacked by numerous flies and in any case were very net shy with the result that many flies settling on them were missed by the catchers.

On the occasion when the trained oxen were used during the forenoon two flies only were captured in the transects, but along the bush edge nine flies were taken off the oxen in thirteen minutes. Of the nine flies captured five were females.

On the occasion when the trained oxen were used in the late afternoon three flies had been captured on the 200 yards transect in ten minutes and on the 100 yards transect eight flies had been captured in fifteen minutes. At the end of the experiment the cattle were walked along the bush edge and in seven minutes ten flies were captured, the female percentage being 25.

The young and partly trained oxen used in the other experiments became too restless at the bush edge to allow flies to be captured off them, but the impression was gained that fly on the bush edge were fairly numerous.

Summary of Experiments on the Range of Flies from Bush.

(1) A party of five men and three oxen walking through long grass and under dry season conditions failed to attract fly (*G. swynnertoni*) to them from fly bush at a distance greater than 100 yards.

(2) The average number of flies attracted out to the party when passing at a distance of 100 yards from the edge of the fly bush for an average time on each occasion of 17 minutes was approximately eight flies.

(3) Of the total of 61 flies captured on the 100 yards transect 59 flies were captured off the cattle.

(4) A marked fly preference was shown for two of the oxen ; only 3·39 per cent. of the flies taken off the oxen were captured from the third ox.

(5) In a similar set of five experiments made later in the dry season over ground which had been partly burnt, giving conditions of excellent visibility, a party composed of four men and three oxen failed to attract more than a few flies from the bush edge. Out of a total of 17 flies captured one was taken at 300 yards, four at 200 yards, and twelve at 100 yards. The average time taken to complete the 100 yards patrol in this set of experiments was 14 minutes.

(6) The flies were shown on two occasions to be in considerable density on the edge of the bush adjacent to the transects.

SOME OBSERVATIONS ON THE SEASONAL SPREAD OF *GLOSSINA PALLIDIPES* IN ITALIAN SOMALILAND WITH NOTES ON *G. BREVIPALPIS* AND *G. AUSTENI.*

W.

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(Plates X–XII.)

Introduction.

The presence of *Glossina pallidipes* in the great tsetse belts of Central Tanganyika has long been recognised, but owing to its relative scarcity in comparison with *G. morsitans* and *G. swynnertoni* it has not merited hitherto the attention and study which has been devoted to these latter species. Whereas *G. morsitans* and *G. swynnertoni* readily attack human beings as well as animals, it is the habit of *G. pallidipes* to show, if not a marked antipathy towards human hosts, then a marked preference for animal hosts, and it is this characteristic which, in the study of sleeping sickness, has caused relatively little attention to be directed towards this fly.

Reclamation measures against *G. morsitans* and *G. swynnertoni*, based upon knowledge of the ecology of these flies, have now developed sufficiently to permit of extensive operations. It is probable that any large scale reclamation measures directed towards the elimination of these flies will have to contend also with a population of *G. pallidipes*.

It is in order to ensure that such measures may be successfully and economically undertaken that an investigation of the ecology of that fly has been decided upon.

It was with the view of gaining some insight into the conditions under which *G. pallidipes* flourishes in Italian Somaliland, and in order to compare the habitat in those regions with the habitat with which the fly is associated in East Africa, that a month was spent in investigating the ecology of the fly in Italian Somaliland.

The Genale area of the Uebe Scebeli was investigated from 23rd January to 5th February, 1935, and Alessandra and Ionte, on the Juba River, were visited from 8th to 12th February, 1935.

Climate.

The climate of Italian Somaliland is influenced by the monsoons. From December to April the north-east monsoon blows, the conditions being dry and hot and the winds of moderate force. During the period June to September the south-west monsoon blows with considerable velocity, producing mild, cloudy weather. There are two rainy seasons : the small rains occur between September and November and the heavy rains, which occur between the two monsoons, fall between the months of April and June.

A brief comparison of the meterological data from Italian Somaliland river stations with the figures from the Shinyanga station shows that the former areas experience higher mean maximum and higher mean minimum temperatures, with less mean difference between them, than does the Shinyanga area. A marked feature of the Italian Somaliland river areas is the consistently high relative humidity. The average relative humidity for Genale on the Uebi Scebeli for the years 1933–34 varies between 80·1 per cent. and 97·0 per cent., and for Alessandra on the Juba River for the same period the variation is between 76·5 per cent. and 86·0 per cent.

The variation in relative humidity for Shinyanga in Central Tanganyika is, on an average, between 31·5 per cent. and 59·5 per cent.

Physical Features.

The interior is formed of a calcareous plateau 1,500 to 2,000 feet (450 to 600 metres) in altitude. Between this and the sea there is a zone made up of granite ridges and alluvial matter. This formation contains isolated outcrops of granite, gneiss and dolerite. Parallel with the coast and running along the margin of the sea there is a continuous chain of sand-dunes. On the sea side these dunes are mobile and on the land side stationary. *Acacia spirocarpa* and other species of *Acacia*, as well as scrub, cover the land side ; the sea side of the dunes is almost devoid of vegetation. The dunes vary in altitude, but as an average height the figure 250 feet (76 metres) may be given.

The basins of the Uebi Scebeli and the Juba are composed of a dark clay soil similar to the " mbuga " soil of East Africa. The breadth of clay soil adjoining the rivers increases as the rivers approach the sea.

The Uebi Scebeli does not drain into the Indian Ocean, but goes underground at Ballei Uen, about 25 miles to the north-east of Gelib, on the Juba.

An extremely interesting feature of the Uebi Scebeli is that its banks are considerably higher than the surrounding country and at times of maximum volume the waters of the river must themselves be above the level of the surrounding country, which is very flat, and rain water and, in past years, river flood water, form considerable areas of marsh land. In these low-lying and moist regions grass and reed growth is very rank and small *Acacia* trees and scrub form dense and shady cover.

Trypanosomiasis in Italian Somaliland.

Tabanids, which transmit trypanosomiasis mechanically, are a far greater factor in the spread of the disease than are tsetse, which transmit it by the cyclical method.

Tabanids are responsible for the spread of *Trypanosoma evansi*, *T. vivax* and *T. cazalboui*, the trypanosome of cattle and camels. A mixed infection of the latter two trypanosomes is sometimes found. Tsetse are responsible for the spread of *T. congolense* and *T. brucei* ; the latter is not, however, fatal to camels.

Factors influencing the Selection of the Genale Area for Investigation.

Barrier-clearing, *i.e.*, cutting off from tsetse bush the country which it is intended to render fly-free, has become an integral part of reclamation measures. The value of such clearings depends, of course, on their effectiveness in confining tsetse to a block of bush the boundary of which is determined by the margin of the barrier-clearing.

In relation to *G. morsitans* and *G. swynnertoni* much has been done to determine the minimum effectual breadth of barrier-clearings, but owing to lack of material it has not been possible to obtain information on this point relative to *G. pallidipes*.

As a permanent barrier against the advance of tsetse, clearings supported by settlement have been employed. Suppression of the natural vegetation by natives and stock is the motive of this measure. But, again, little or no information is available regarding the ability of *G. pallidipes* to penetrate a settled and cultivated area in which the vegetation is much reduced. Information on the degree of sparseness of the vegetation necessary to preclude *G. pallidipes* from the settlement would be of great value. The difficulties of staging experiments to throw light on these questions are at once apparent.

It was felt that at Genale had fortunately been found an unprepared large-scale experiment in the penetrating powers of *G. pallidipes*, and that probably nowhere else could such conditions be found. Conditions obtaining in this area resemble in many respects those of a settlement clearing. The area is open, cultivated and settled and abuts upon a dense fly population. The factor of irrigation is not likely, it is true, to be encountered in a settlement clearing, but conditions of a wet soil and high relative humidity may well be produced during a season of heavy rainfall.

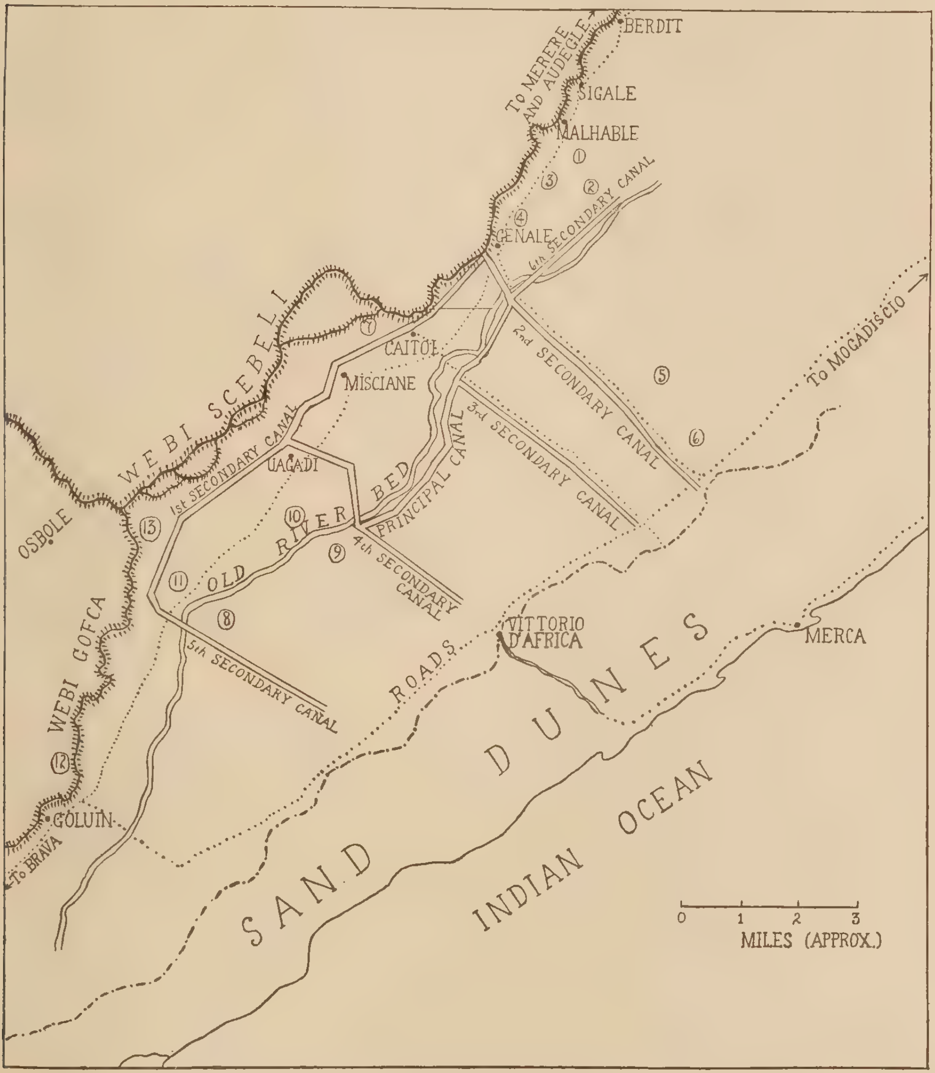
BERDIT
To MERERE AND AUDEGLE
SIGALE
MALHABLE
①
②
③
④
GENALE
6th SECONDARY CANAL
WEBI SCEBELI
⑦
CAITOI
MISCIANE
2nd SECONDARY CANAL
⑤
⑥
To MOGADISCIO
1st SECONDARY CANAL
UAGADI
OSBOLE
⑬
⑩
OLD RIVER BED
PRINCIPAL CANAL
3rd SECONDARY CANAL
⑨
4th SECONDARY CANAL
⑪
⑧
WEBI GOFCA
5th SECONDARY CANAL
ROADS
VITTORIO D'AFRICA
MERCA
SAND DUNES
⑫
GOLUIN
To BRAVA
INDIAN OCEAN
0 1 2 3
MILES (APPROX.)

Fig. 1. Genale area of the Uebi Scebeli. Numbers indicate farms referred to in the text.

Trypanosomiasis in the Genale Area.

Examination of blood-slides taken from sick cattle in the Genale area has on numerous occasions been undertaken by officers of the Veterinary Department.

The results of these examinations have incontrovertibly shown that infections of *T. congolense* are prevalent within the area.

Very little livestock is kept by Europeans in the area now, and such as are kept are mostly maintained on farms remote from the river. The natives living in the area and in villages near by have small herds of mixed stock and one or two camels were seen.

Some years ago (1928) 400 working oxen were introduced into the area and, prior to their distribution among the farmers, blood-slides were examined and found negative, and yet within four months of the date of distribution all the animals had died of trypanosomiasis. The greatest care had been taken to ensure that the cattle did not come into direct contact with fly bush. Indeed, it is the practice to graze and water stock on the farms and not to allow the animals to go near the river.

Vegetation of the Genale Area.

The map (fig. 1) shows the course of the old river-bed running close to and almost parallel with the present course, but to the east of the latter. The old river-bed has a fairly dense vegetation growth, but the Uebi Scebeli itself is almost devoid of vegetation owing to intense native cultivation, especially along the left bank.

In the area remote from the river and the old river-course a type of vegetation suited to the drier conditions is met with. The grass growth in these areas is scanty and the bush sparse and of a scrub type. *Euphorbia* is noticeable, particularly in the west of the Genale area between the Uebi Scebeli and the Uebi Gofca (or Gof) to the north of Goluin on the extreme left of the map.

The vegetation along the river banks rarely exceeds a few yards in breadth, but occasionally spurs of vegetation reach a distance of one or two hundred yards from the bank. The north side of the Uebi Scebeli, from Merere to Goluin, is very open. Grassland runs right up to the river and extends away as far as the eye can see. Large *Ficus* trees are spaced along the bank and occasionally thickets of *Acacia arabica* and *A. Benthamii* are met with. The grass on the river banks is tall and coarse and frequently large areas of reeds are noted. Even during the dry season the grass is green and the acacias are in leaf. Plate X, fig. 1, gives a view of the north bank of the Uebi Scebeli from Malhable.

The south bank of the river has extensive sections of vegetation along its margin. *Ficus* are to be found spaced along this bank growing, as on the north bank, on the water's edge. It has already been noted that the banks of the Uebi Scebeli are higher than the surrounding country, and it is in the moist soil adjacent to the river and actually below its level that the densest vegetation is to be found. The wooding of the south bank is similar to that of the north bank in that the dominant species are acacias, and these growing closely together frequently form thickets extending over considerable areas. From this marginal growth scrub and stunted trees stretch away towards the dunes to the east. Rain-water standing in the low ground remote from the river gives rise to strong growth of coarse grasses and stunted trees.

Plate X, fig. 2, gives an impression of the south (left) bank of the Uebi Scebeli. The *Ficus* trees on the river edge are clearly shown, as are the matted coarse grasses on the bank. The acacias growing below the level of the river bank are seen on the left of the picture. Plate X, fig. 3, shows an acacia thicket growing close to the river. It will be noticed that the density of the thicket is increased by the strong growth of long grass around the base and by the *Cissus* sp. climbing over it. This photograph was taken after the annual fire had been through the area. It may be assumed that during the wet season and before the fires the growth of the grasses and *Cissus* is very much more dense than shown in the photograph.

An impression of the bush forming the transition between the marginal acacia and the deciduous scrub is given in Plate X, fig. 4. This belt is composed of stunted, or probably regenerated, acacias, *Balanites* and *Thespesia*, interspersed with large bushes of *Solanum*.

Description of the Genale Farming Area.

At Genale is situated a large dam across the Uebi Scebeli, and here also are situated the Agricultural Department's headquarters for the area and the Experimental Farm. This section of the area is well planted with wind-breaks and avenues extending over a wide area to the east of Genale itself, but in the newer sections the holdings are much less heavily planted with trees, or it may be that the trees have not yet grown sufficiently to become noticeable. Plate X, fig. 5, gives an impression of the open conditions to be found over the greater part of the area.

The acreage put down to any one crop depends upon the economics of supply and demand, but in the matter of bananas a market has been assured in Italy by means of tariff legislation and consequently this crop tends to form the main product of the area. Each holding has a set acreage under bananas, but the cultivation of this crop on farms remote from the river is discouraged, since the loss of water for irrigation is so great at a distance from the river that the undertaking becomes unprofitable. Farmers with holdings remote from the river have been given in compensation plots of banana land on the north side of the river and in some instances plots have been allotted on the south side of the river in the locality of Malhable and Sigale to the north-east of Genale.

Other crops grown are cotton, maize, castor oil plants, kapok, ground-nuts and tropical fruits, as well as vegetables and, to a small but increasing extent, grapes. Two harvests a year are reaped from the main crops. It is interesting to note that as yet manuring is not considered necessary.

About the year 1912 a start was made to develop under irrigation from the Uebi Scebeli a section of land at Genale on the south, or lower, side of the river. Since that time development has gone forward until, to-day, the whole of the south side of the river from Genale to Goluin to a depth of about five miles (8 kilometres) is under an intensive system of irrigation. Since the banks of the river are above the level of the surrounding country and the land is itself extremely flat and of very gentle contour, no pumping plant is necessary and no complicated system of water distribution is required.

A large cement dam has been thrown across the river at Genale in order to bank up the water during seasons of low volume. From the main canal, which takes off from the dam, a number of minor canals distribute the water as required.

The area is divided into about 100 farms averaging from 150 to 180 hectares in extent, which are in a high state of cultivation although maximum development has not been reached ; it is intersected by an excellent system of good roads and many miles of light railway have been laid down.

Eight dressing stations have been built and there is one hospital to which ward cases may be sent. There are a number of native villages and each holding has its farmhouse and out-buildings.

Owing to loss of stock from trypanosomiasis motor tractors are largely used for cultivation purposes, and for conveyance motor cars and lorries are in general use. Most of the traffic tends to converge from the farming area on Vittorio d'Africa, for at this point are situated the offices of the co-operative society and the cotton ginnery. The road to Merca takes off from the main coast road at this point and is in constant use, as bananas for export are shipped to Merca.

Bush fires of great intensity sweep through the country during the dry season and may be a factor in eliminating far-wandering fly. The fires along the river edge are patchy and fail to reduce the undergrowth to any extent owing to its humidity.

Game is scarce over the greater part of Italian Somaliland as compared with other parts of East Africa. Along the stretch of river from Merere to Goluin the following game is present :—waterbuck, dikdik, bush-pig, monkey, baboon, hyena, jackal, porcupine, hippopotamus, crocodile and leopard. The name " Uebi Scebeli " means river of leopards. In time past leopards were numerous on the river, but now they are comparatively rare. Dikdik are very common in the drier parts.

The Tsetse Position.

Glossina pallidipes, the only species of tsetse found on the Uebi Scebeli, is confined to the immediate vicinity of the river during the dry season, but during the wet season the fly is said to spread as far as 6 miles (10 kilometres) from the river. Croveri (1919) considers that high humidity is essential to *G. pallidipes* and attributes its ability to range so far to the presence of marshy areas, caused by standing rain-water or by river flood-water, which provide at once local high humidity and shade. Owing to the clay soil the water remains for long periods in depressions and *G. pallidipes*, having once reached an area of standing water and shade, is capable under the mild and cloudy conditions of the wet season to make a base of such a locality from which further spread is possible.

Little information could be obtained on the seasonal increase in fly density. Opinion has it that an increase in the number of tsetse does take place during the wet season and seasonal spread is held to be evidence of increase in density.

An extremely interesting and important statement was made by Dr. Falcone and Captain Riva, of the Sierovaccinogeno Institute, to the effect that purchase of fodder grass cut along the banks of the Uebi Scebeli had to be discontinued for the reason that an outbreak of trypanosomiasis amongst the Institute's cattle was traced to the presence of live tsetse-fly within the bundles of grass brought to the Institute from the river. Tsetse were extremely rare along the river at the time when this investigation was carried out, and their discovery in these bundles of grass suggests that they must have been much more numerous at that time.

At the time of my first visit fly density was at its lowest and fly were confined to localised areas. In the months of May, June and July fly are known to spread in small numbers all over the farming area and individuals have been captured on the dunes, a distance of over five miles from the river. The scope of the investigation was therefore narrowed down to a study of the vegetation affording passage to the fly through the area.

For clarity, the extent of the country covered has been divided into three sections, comprising the country adjacent to the Genale area on the east, the Genale area, and the country immediately to the west.

The East Section.

Morning and evening fly catches undertaken up-stream as far as Berdit (see Map) and beyond failed to reveal fly.

As a point easily reached by car and as one representing permanent fly bush, Gioar, slightly down-stream from Audegle, was visited. This point does not represent the nearest permanent fly bush to Genale, being some 12 miles to the east of that place, but it is thought to be a centre from which extensive fly distribution takes place during the wet season. The nearest permanent fly bush to Genale, up-stream, was not determined, but it is certain that no true permanent home of *G. pallidipes* is to be found between Genale and Berdit.

At Gioar the marked contrast between the marginal vegetation and the vegetation more remote from the river is clearly seen. Along the banks of the river and forming a tall background are spaced many *Ficus sycamora*. Dense thickets of *Acacia arabica* and *A. Benthamii*, in many cases reinforced with great masses of *Solanum* and supporting a broad-leafed species of *Cissus*, are intermixed with deciduous thicket, thought to be of *Dobera* sp. and *Thespesia* sp. with *Harrisonia abyssinica*. It is this mixture of acacias (which appear always to be in leaf) with deciduous thicket that is thought to be the true habitat of *G. pallidipes* on the Uebi Scebeli itself.

The thickets are not continuous but are broken up into comparatively small blocks by glades and small open spaces which support a low-growing quick-grass, abundant and green. The thickets, which rarely extend more than 300 yards from the river bank, follow the course of the river as a narrow fringe. Beyond the riverine strip the vegetation changes abruptly to deciduous scrub composed mainly of *Dobera* sp. and *Thespesia* sp. The presence of a native settlement at Gioar ensures that the vegetation in the locality is well suppressed.

In the wet season the scrub carries full leaf and this affords sufficient shade for *G. pallidipes* to spread far out from the riverine thicket to which it is closely confined in the dry season. Wet season radiation of fly from the river is in this area now a far less serious matter than it was in previous years. Irrigation engineers have prevented the annual flooding of the area by the Uebi Scebeli, and, in consequence, large swamps caused partly by drainage of rain-water but more particularly by river flood-water have become greatly reduced in size with a consequent change in the vegetational communities less favourable to the fly.

A party consisting of three Europeans and two African assistants, with a screen, conducted a fly catch in the thicket area. The catch, which lasted for forty minutes, commenced at 7.55 a.m. and was conducted under the following weather conditions : Sun bright, cloud 0 (later 3), wind 0/I. The catch was made in the glades and open spaces between individual thickets. Fly were taken only in this locality ; no fly were taken along the thicket edge remote from the river. Fly were taken as follows : III, III, IV ; female percentage nil ; M.H.S. 3·33*.

Following the catch an hour was spent in searching for pupae. While crawling about in the thickets and searching breeding sites the party was attacked by a number of tsetse, the majority of which were sluggish and disinclined to probe. Seven flies were captured of which six were IIIs and one stage I. Although it is not thought that the thickets harboured any great density of fly, it is clear that repletion rather than scarcity was the factor influencing the low numbers recorded for the catch. Three empty cases only were discovered during the search, but it is interesting to note that they were all taken from under the low-growing branches of deciduous thicket and not from under the more shady acacia trees. The soil in the thickets was extremely hard, but the surface was covered with dry leaves and trash. Leading up from the river and passing through the thickets was a much used hippo path. Monkeys were present in the thickets.

At Malhable and at Sigale, up-stream from Genale, are two native villages, and between these two points there is a considerable amount of marginal wooding, continuous and often closely-growing. On the south side of the river and at a distance of about 500 yards from the river and parallel with it a large area has recently been cleared and planted with bananas. On the further side of the plantations, remote from the river, is the area of deciduous bush mixed with regenerated acacia, occasionally very dense, which stretches away to the sand dunes. Connection between the riverine wooding and the deciduous bush is still maintained by narrow strips of natural vegetation retained to demarcate the boundaries of the banana plantations.

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* Tsetse-flies may be divided into four stages of hunger by the external appearance of the abdomen, viz. : Stage I, gorged ; Stage II, replete ; Stage III, intermediate ; Stage IV, hungry. By a simple calculation the Mean Hunger Stage (M.H.S.) of a sample of flies may be determined. The calculation is worked to two places of decimals. A state mid-way between satiety and hunger would receive the value 3·00. Figures having a value higher than 3·00 indicate that the flies in the sample are on an average more hungry than replete. Values lower than 3·00 indicate a state of repletion rather than hunger. The degree with which the values vary about the mean will be influenced by the degree of repletion or hunger in the sample. Females and young flies are not included in the calculation. Females, other than pregnant females, are described as F4.

The marginal bush (Plate X, figs. 2 and 3) is dominated by *A. arabica* and *A. Benthamii*; *A. orfola*, *Thespesia* sp., *Balanites Scilan*, *Salvadora persica* and *Solanum* sp., are abundant, while *Kigelia* sp. (*somaliensis* ?) and *Dobera* sp. are frequent. The acacia trees are much overgrown with *Cissus* sp.

The absence of deciduous thicket types, such as were noted in the Gioar area, is thought to be an important point.

In the deciduous scrub area low-growing specimens of *A. arabica* and *A. Benthamii* are the dominant species, but at a distance of about 600 yards from the river the vegetation becomes thinner and the acacias are less frequent. *Balanites Scilan*, *Thespesia* sp. and *Solanum* sp., growing as stunted bushes, become dominant in the drier area away from the river. *Euphorbia candelabra* and *Salvadora persica* are frequent in the area, as is *Dobera* sp.

On four occasions fly catches were undertaken, both in the early morning and in the late afternoon, in the marginal wooding and in the dry scrub country. On one occasion a *G. pallidipes* is thought to have settled for an instant on the screen during a catch in the interzone. Otherwise no indication could be had of the presence of fly at that time in the area.

One day was spent searching for pupae in the bush between Malhable and Sigale, but no evidence of their presence could be found. It is thought that the absence of deciduous thicket, which forms the only apparent difference in the vegetation of this area from that of the Gioar area, may be a factor rendering the Malhable-Sigale bush unfavourable to *G. pallidipes* during the dry season.

It is unfortunate that the native word " ghendi " includes all species of biting flies, for no clear understanding could be had as to whether a native was or was not differentiating in his evidence between tsetse and Tabanids. The consensus of opinion, including that of Europeans, is that tsetse are numerous in the Malhable-Sigale area during the wet season. This investigation has shown them to be absent during the dry season.

The stretch of river between Genale and Sigale is very open, and so also is the country to the south-east of the river. Holdings have been surveyed in the extreme north-east section of the area (1, 2, 3 on Map). These farms were not under cultivation at the time of this investigation, and the photograph (Plate X, fig. 6), taken from the bank of the sixth secondary canal towards the river, shows the open nature of this stretch of country. The *Ficus sycamore* in the distance indicates the position of the Uebi Scebeli. Maize, growing on farm 4, can be seen on the left of the picture, while on the extreme right can be seen the line of the bush of the Malhable area. Plate XI, fig. 1, taken from the same position as the previous photograph, shows more clearly this latter bush and also shows a section of the deciduous scrub.

The farms to the south of the sixth secondary canal make contact on the east with the scrub bush to the south of Malhable. At a point somewhere to the east of farm 5 this scrub starts to thin out considerably until open ground is encountered to the east of farm 6. It will be seen from the map that the sixth secondary canal runs close to and along the line of the old river-bed. The suggestion was made that fly penetrate the Genale farming area from the east by means of this canal. Plate XI, fig. 1, shows the type of vegetation growing along the north side of the canal, and Plate XI, fig. 2, which was also taken from the bank of the canal, shows the type of vegetation growing along the south side of the canal. On the latter side the vegetation is made up of isolated clumps of low-growing *Acacia* and an avenue of young *Casuarina*. The line of contact between the easterly farms and the deciduous scrub was not surveyed, but it is thought probable that contact is made on a front of about 3 miles (4·5 kilometres). In view of the distance of this bush from the river, together with the open nature of the cultivated area and of the canal banks, the theory that tsetse penetrate the Genale farming area from the east is not one to which unconditional agreement can be subscribed.

The Genale Area.

At Genale and at Caitoi, down-stream, a considerable amount of tree-planting has been done, and the roads in the vicinity of these two places have avenues of *Cassia florida*, *Ceiba pentandra* (kapok), *Casuarina* sp., *Tamarindus* sp., *Terminalia* sp., and coconut palms, as well as hedges of *Cassia floribunda* and *Caesalpinia pulcherrima*.

Between Genale and Caitoi the river is singularly open, the only trees being *Ficus sycamora*. Along the river front of farm 7, to the west of Caitoi, the vegetation is in places very dense. Cultivation restricts the vegetation to a narrow strip having a maximum breadth of perhaps 200 yards. At this point dense masses of *Solanum* are banked up against closely-growing *A. arabica* and *A. Benthamii*, while *Thespesia* is much in evidence. These species are the dominants of the riverine vegetation which, confined to narrow limits by cultivation, stretches, it is believed, discontinuously along the south bank of the Uebi Scebeli from Caitoi to the junction of that river with the Uebi Gofca. The north bank of the river appeared to be more open than the south bank, and now, since bananas are being planted along the north bank, it is probable that the vegetation on that bank also is purely marginal.

Much time was spent with a screen and a calf in an endeavour to obtain evidence of *G. pallidipes* in the bush along the river in the Caitoi area. No evidence of tsetse occupation could be obtained, nor could pupae be discovered. It is therefore concluded that occupation of this section of the river, and probably for some way down-stream, is a seasonal occurrence. The statements made to the effect that outbreaks of trypanosomiasis are more frequent on the river farms during the wet season would seem to lend support to this conclusion.

Away from Genale and Caitoi, the nuclei of the area, wind-breaks and avenues become less frequent, the centre and western sections being very open. Small plantations of kapok, in the Genale and Caitoi sections, show up very plainly. Search for tsetse was made in one of these plantations, but without success, the lack of undergrowth and the absence of low canopy rendering them unsuitable.

Along the banks of the principal canal, which follows very closely the old river-bed, a strip of natural vegetation still remains. This vegetation varies in density and size along the course of the canal, but in composition it is very constant ; its extent along the principal canal varies from tongues of bush extending to a distance of 300 yards from the canal bank to individual bushes growing close under the bank. As an average, 50 yards may be given as the extent of the bush from the canal. The species encountered are similar to those found along the river (Plate XI, figs. 3 and 4). The vegetation bordering the subsidiary canals which take off from the principal canal and run south-east through the area is very limited and is frequently confined to grasses only.

The list of trees and plants which follows refers to the vegetation along the principal canal and the principal secondary canal and to a minor extent to the sixth secondary canal. Owing to the absence of flowers and fruits many species growing along the canals could not be identified.

Co-dominant ...	*Acacia arabica* and *A. Benthamii*.
Very abundant ...	*Thespesia* sp. and *Solanum* sp.
Abundant	*Salvadora persica* and *Cordia Gharaf*.

Frequent	*Capparis* sp., *Harrisonia abyssinica, Indigofera* sp., *Gymnosporia senegalensis, Cissus* sp., *Balanites Scilan, B. racemosa, Dobera* sp., and *Euphorbia candelabra.*
Occasional	*A. Seyal* and *Agave* sp.

Frequent fly catches were undertaken along the principal canal with screen and calf, but no fly were taken. Numerous searches were made for pupae at various points along the canal, but the results were in every case negative. The search for fly was so thorough that, had fly been present, a specimen would almost certainly have been taken.

At the junction of the old river-bed and the fifth secondary canal, farm 8, there is a large patch of natural bush which escaped clearing operations at the time when the area was being prepared for cultivation. This piece of bush, which is about 320 yards broad and perhaps twice as long, is very representative of the vegetation both of the river and of the dry country remote from the river. As in other instances, *A. arabica* and *A. Benthamii*, much thickened by *Cissus*, grow very densely along the canal bank. Deciduous bush, of a type more robust than hitherto encountered, covers the ground to the south of the canal. *Euphorbia candelabra* and *A. orfola* were found growing very strongly. *Balanites Scilan, Dobera* sp., and a deciduous bush, thought to be a *Grewia*, were in considerable profusion. Other species already enumerated were also present. Spoor and dung of small buck were plentiful.

A fly catch, starting at 4.33 p.m. and lasting for 52 minutes, was conducted with a screen in both the marginal bush and the deciduous bush. During the period eight flies were taken, all of which were captured in the marginal *Acacia*. The flies were taken as follows : IV, F4, III, IV, III, I, F4, III. This gives a M.H.S. of 3·40 and a female percentage of 25.

It is interesting to note the presence of deciduous thicket types (*Grewia* sp.) in this fly bush. It will be recalled that the permanent fly bush hitherto encountered was at Gioar at which place deciduous thicket was also present.

The fly bush on farm 8 is separated from the marginal bush of the principal canal to the east by a distance of about 2 miles (3 kilometres). Between the fly bush on farm 8 and the boundary of farms 9 and 10 the country is very open and the canal is devoid of bush along its banks. The country to the south and south-west is also very open and is entirely under cultivation, but to the north-west on farm 11, in the bend of the first secondary canal, there is a block of natural vegetation.

It has been said that stock may be kept on the farms along the Uebi Scebeli during the dry season without much fear of attack by tsetse. Along the Uebi Gofca this is quite out of the question, for stock kept on these farms will at once contract trypanosomiasis. In fact the practice of keeping stock on any of these farms has long been discontinued.

In view of the occupation by tsetse of the bush on farm 8 it is thought extremely probable that the block of bush on farm 11 is also infested with *G. pallidipes*. Plate XI, fig. 5, shows a stretch of the first secondary canal and in the distance on the left can be seen the bush on farm 11 ; the photograph shows the open nature of the canal for a distance to the east of the bed in the canal. Plate XI, fig. 6, has been included to show a typical piece of bush along this canal ; the photograph was taken about 300 yards further along the canal, to the east, from the point from which the preceding photograph was taken.

At the time when the area was visited the harvesting of the annuals had been completed, and except for the area on each farm under bananas the greater part of the holdings was fallow.

The banana plantations are laid out on the orchard, or quincunx system, the soil being well cultivated and kept entirely free of weeds. The banana plants are stripped of leaves up to a height of about 3 ft. 6 in. from the ground.

The West Section.

The country for a mile or so round the large native settlement of Goluin is much overgrazed and reduced by wood-cutting. Along the west side of the Uebi Gofca *A. arabica* and *A. Benthamii* are found, but their distribution is confined to a marginal strip parallel with the Gofca. During the dry months of the year there is no water in the Gofca, the water being held up by a dam thrown across the Uebi Scebeli upstream from the junction of the two rivers. A large irrigation canal follows very closely the course of the Gofca.

The bush to the west of the Gofca is typical of the arid plains of south Somaliland and is composed largely of *Euphorbia* and *Acacia*. The following species were identified : *Euphorbia candelabra, Salvadora persica, Balanites Scilan, Solanum* sp., *Cordia Gharaf, Dobera* sp., *Grewia* sp., *Cissus quadrangularis, Acacia spirocarpa, A. Seyal, A. orfola, A. pinnata* and *Agave* sp. A species of *Euphorbia*, not identified but closely resembling *E. candelabra* in form, has a wide distribution in this area. Plate XII, fig. 1, shows a section of this region.

Between the Uebi Gofca and the country of which the vegetation has just been described, there is an area of dense deciduous thicket, the limits of which can be given only approximately, but it is thought to extend from a point on the west side of the Gofca, opposite farm 12, to a point opposite farm 13, south of the junction of the two rivers. At this point the thicket is thought to be about 3 miles (4 kilometres) broad, while at its southern end it is thought to be about one mile broad. At the time when this area was visited clearing operations were being undertaken to open up fresh ground for banana plantations, which will reduce the area of the thicket very considerably. Plate XII, figs. 2 and 3, show very clearly the dense and deciduous nature of the thicket. Little identification of species could be done owing to the absence of leaves, flowers and fruits. Euphorbeaceae, Combretaceae, Capparidaceae and Mimosaceae were, however, noted. The thicket, although impenetrable in many places, was on the whole fairly open beneath a matted canopy. Progress could be made from one point to another in the thicket without much difficulty provided that a crouching attitude was assumed.

At the time of an early reconnaisance through the country to the west the presence of dense thicket was not suspected, as the vegetation map which the author had at his disposal did not give prominence to this type of bush. The capture of one *pallidipes* off the car during the reconnaisance prompted the belief that a fly centre might be encountered in the neighbourhood. In view of the absence of permanent fly bush on the east flank of the farming area and in view also of the low numbers of fly encountered within the area itself, some concern was felt to discover the source from which the seasonal spread took place, since the vegetation map gave no indication of an association in the west likely to support a permanent fly population.

From the point at which the single specimen of *pallidipes* had been taken at the time of the car reconnaisance, a start was made later on a foot reconnaisance to discover the centre from which the fly had radiated or from which it had been carried. It was fortunate indeed that shortly after reaching the starting point a number of women carrying bundles of firewood on their backs were encountered. It was noticed that beneath one of the loads a *pallidipes* was resting. The track along which the women had been walking was followed. Later cross-paths were met with which rendered it difficult to determine which direction to pursue. However, within twenty minutes two women carrying sticks and going towards Goluin were found to be carrying three flies and the direction whence they had come was followed. In this manner we were eventually led up to the thicket area. It was 11.30 a.m. when we reached the thickets and fly activity had almost ceased, only one female fly being taken during a short preliminary survey. A search for pupae showed indications of considerable fly density. Sixty empty cases and three pupae were found. Preference for breeding seemed to be shown for large horizontal growing *Acacia* trees, as against the bases of thicket types. The soil in the sites was dry and friable and not smooth and hard as was noticed along the river.

The day following the foot reconnaisance a fly catch with a calf was done in the thicket area. The party was composed of two Europeans and four natives, three of whom were trained fly-boys and the fourth a member of the African staff of the Italian Veterinary Department. The route taken was at first along a road between the thicket and the cleared area, piled ready for burning, and later through the thicket by a narrow survey path. The fly catch is detailed below :—

Time, 8.10 a.m. Conditions, sun faint, clouds 8, wind 2/3.

Temperature, 76·0°F. (24·4°C.). Relative humidity, 78 per cent.

Time	*Fly*
8.10	YF.
8.14	IV, III.
8.17	F4, F4.
8.24	IV.
8.27	YF.
8.40	IV.
8.44	IV, IV.

At 8.35 a.m. the party had left the road and the catch was continued along the narrow survey path between the thickets. During the catch, which has been recorded above, the behaviour of the flies was thought to be abnormal, in that they were extremely active, but appeared timid of probing although apparently anxious to do so. It was thought that the flies were being confused by the presence of so many humans round the calf. Two Europeans and one African assistant were withdrawn from the vicinity of the calf and at once a change was discernible in the behaviour of the flies, for they settled on the calf and began to feed immediately. This made catching much easier and a higher number of captures was recorded.

Time	*Fly*
8.47	F4.
8.50	III, F4, F4, F4.
8.53	III.
8.53	Temp. : 82°F. (27·8°C.), R.H. 64 per cent.
8.57	F4.
8.58	YF.
9.00	F4.
9.02	III, III.
9.06	III.
9.08	F4, F4, F4, IV.
9.10	F4, F4.
9.14	F4, YF, III.
9.15	F4.
9.16	F4.
9.17	F4, F4, F4, III.
9.20	F4, F4.
9.24	III, F4, F4, F4.
9.25	Young male.

Calculating from the time that the three members of the party withdrew from the vicinity of the calf (8.46 a.m.), flies were taken at the rate of 54 per hour. M.H.S., 3·11. Female percentage, 70·97. Young percentage, 9·68.

Information was given to the effect that the thicket stretched as far as the Uebi Scebeli, but observations made from Osbole (see map) showed a steppe of native cultivation along the river frontage to a depth of about one mile. Records on the vegetation map show very open ground at the junction of the Uebi Scebeli and the Uebi Gofca. This point is of importance, since a connection between the Uebi Scebeli and the thicket would explain the infestation of the riverine bush by *G. pallidipes* in the wet season. It is much regretted that a survey of the country to the north-east of Osbole was prevented by unforeseen circumstances.

A Theory of the Mechanism of the Seasonal Spread of G. pallidipes through the Genale Farming Area.

The clearings on the west side of the Gofca are of recent origin, and statements made in connection with the seasonal spread of *G. pallidipes* into the farming area were based on observations made prior to the commencement of the operations.

The density of the population of *G. pallidipes* in the thickets along the west bank of the Uebi Gofca increases during the wet season of the year. This increase is due to a number of factors, among the more important being increased longevity and consequent increased breeding period and increased fecundity brought about by congenial conditions as well as by a lengthening of the period of digestion.

At the time when the thicket is in leaf during the wet season visibility becomes much restricted and tsetse find difficulty in locating their hosts. The game, which during the dry season water at the Gofca and at its adjacent canal (not shown on map), disperse during the wet season and drink at the pools which form all over the country during the rains.

These two factors, restricted visibility and game dispersal, cause the fly to range out from the thicket in search of food. Cool and cloudy conditions combined with high humidity and tree shade are favourable to the fly, and under them the fly can maintain itself without the necessity of returning to the thicket except for larva deposition.

G. pallidipes leaving the thicket area and flying east would find in the banana plantations conditions both cool and shady. Fly issuing from the north-east side of the thicket would at once find favourable conditions in the block of natural vegetation on farm 11, and, further away, in the block of bush on farm 8. Fly following the Gofca in a northerly direction would, it is believed, find an uninterrupted line of marginal vegetation leading right up to the Uebi Scebeli. Spread along the river is known to be a seasonal occurrence, and fly radiating from the river in a southerly direction would find in the banana plantations and wind-breaks of that section shade combined with visibility. In the marginal vegetation of the first secondary canal, fly from the Uebi Scebeli would join with the fly which had followed down the canal from the west and a population of considerable density would be formed.

Movement of natives and of motor vehicles would, it is thought, tend to attract fly out into the cultivated areas. A factor in the distribution of fly which must be taken into consideration is the continual passage of wood-cutters carrying their loads of firewood from the thicket into the heart of the area, to Uagadi and to Misciane, and the route frequently followed is along the banks of the first secondary canal. Tsetse have been noticed on the underside of loads of firewood, the spaces between the sticks affording good shade as does the underside of the bundle itself. Plate XII, fig. 5, shows a native woman carrying a load of wood. Experiments and observations on *G. swynnertoni* show that this fly can be carried long distances in this manner, and there is reason to believe that *G. pallidipes*, too, may be carried considerable distances by natives bearing loads.

The distance, as well as the open nature of the ground, between the fly centre on farm 8 and the strip of vegetation along the principal canal would prevent the free passage of fly. Some fly do undoubtedly find their way across, but the majority must spread out to the west and south-west. The wind-breaks in this section of the area, although not numerous, would form leading lines for the fly, which would also take advantage of the banana plantations for shade and rest.

The principal canal is almost certainly infested by fly following the numerous avenues and wind-breaks, as well as taking advantage of the well-grown banana plantations at Caitoi and Genale. From these two points there is continual traffic of natives and along the roads there is much motor traffic. It is not thought that motor vehicles are responsible to any extent for the actual carriage of fly, but it is thought that their rapid movement may attract tsetse to follow and so influence their spread. A motor tractor passing along the side of a banana plantation would probably influence tsetse to move across the plantation in order to inspect and possibly attack. These movements, although small in themselves, are thought to be a factor in drawing the fly away from the natural vegetation of the river and the canals and also from the isolated patches of bush and thereby causing the distribution of fly in small numbers right through the farming area.

Once a foothold has been gained on the principal canal the fly would encounter no obstacle to their spread in a westerly direction from the junction of the second secondary canal as far as farm 10, near the junction of the fourth secondary canal. Thus through the very centre of the farming area is established a concentration from which fly radiate into the cultivated areas to the north and south. Nevertheless, the ability to penetrate into the section south of the principal canal, free as it is of natural vegetation and scantily planted as it is with wind-breaks, offers a very striking example, the more so since it must be remembered that the acreage on each holding planted to bananas forms but a small proportion of the whole, and that in the main the holdings are planted with standing and close-growing crops, such as maize, castor-oil plants and cotton.

In seeking some factor which would tend to mitigate the severe conditions encountered by *G. pallidipes* when penetrating an area of close settlement and intensive cultivation, that of humidity must receive consideration. It may well be this factor, brought about not only by meterological conditions but also by the artificial application of water for irrigation, more than any other that enables *G. pallidipes* to maintain itself for limited periods under conditions which are essentially artificial.

Investigation on the River Juba.

Alessandra.

The vegetation of the River Juba resembles very strongly that of the Uebi Scebeli in that a narrow strip of marginal vegetation follows the course of the river, while the country remote from the river is covered with deciduous scrub in which *Euphorbia* and *Acacia* are frequent.

Near Gelib the Juba is divided by the island of Alessandra, on the south side of which, along the banks of the Ultra Juba and along the west bank of the mainland, are situated magnificent rain forests. There is much cultivation by Europeans and natives on both sides of the river.

Game is fairly common in the area, the same species being present as in the Uebi Scebeli area. Elephants in large numbers visit the rain forests during the wet season of the year.

Glossina pallidipes, *G. brevipalpis* and *G. austeni* are to be found on the island of Alessandra.

Near the village of Beled Armin, on the island of Alessandra, is an area of deciduous thicket in which well-developed specimens of *Zizyphus mucronata* and *A. arabica* are frequent. The following species were also noted : *Hyphaena benadirensis*, *Terminalia Howtii*, *Garcinia Ferrandi*. The thicket is remarkable for its open nature beneath a high and open canopy, and comparatively little difficulty was encountered in walking about in it. The area of the thicket is not known, but is thought to be fairly extensive.

A fly catch was carried out with a screen in the thicket area under the following conditions : Sun bright, cloud 1/4, wind nil. Time 8.10 a.m. Temperature 82·0°F. (27·8°C.). Relative humidity 75 per cent. The party was composed of two Europeans, three African assistants and one native youth.

The area was approached through native cultivation and regeneration and in this section only one *pallidipes* (stage III) was taken.

At 8.20 a.m. the thicket was entered along a path and the following *pallidipes* were captured :—

8.23 a.m.—I, III, III, II, I, III, I, III, III, III, I, F4, F4, III, F4, III.

8.45 a.m.—Thicket became more open with *Hyphaena benadirensis* frequent. Temperature 84·0°F. (28·9°C.). Relative humidity 76 per cent.

9.03 a.m.—F4.

9.10 a.m.—Thicket denser : III, IV, III, III, III, I, IV, III, IV, III, II, III, III, III, III, III, young male, III, I, III, III, young female, III, III, F4, IV, III, *G. austeni* male, III, III, III, III, I, III, III, III.

9.30 a.m.—Temperature 85·0°F. (29·4°C.). Sun dull, cloud 4. Relative humidity 68·5 per cent. : III, IV, I, F4, III, III, III, III, *G. austeni* female, III, I, III, F4, III, III, F4, III, IV, F4, III, III.

10.00 a.m.—Temperature 88·0°F. (31·1°C.). Relative humidity 59 per cent. : III, III, III, F4, F4, IV. Sun bright.

10.05 a.m.—Native cultivation on left, thicket on right-hand side : IV.

10.10 a.m.—Native cultivation : Fly nil.

During the time spent in the thicket (8.20 a.m. to 10.00 a.m.) 78 *pallidipes* were taken. This works out at the rate of 47 flies per hour. M.H.S. 3·11. Female percentage 14·5. Young percentage 2·63. The majority of flies were caught off the ground off leaves and the blades of grasses.

A number of sites were searched for pupae and a preference was noted for fallen tree-trunks. A large number of empty cases of *G. pallidipes* were found under fallen *Hyphaena benadirensis.*

An afternoon fly catch was undertaken in the rain forest on the west side of the island of Alessandra. Shortly after entering the forest a catch was done at 4.40 p.m. under the following conditions : Sun bright, cloud nil, wind 0/2. Temperature 89·0°F. (31·7°C.). Relative humidity 53·5 per cent. The catch lasted for twenty minutes, during which time the following flies were caught : *G. austeni* 2 males and 1 female, *G. pallidipes* 2 females. *G. brevipalpis*, which were very numerous, were not captured.

At a point on the bank of the Ultra Juba, where palm trees replaced the forest species over a small area, a catch was done at 5.10 p.m. Fly were taken as follows : *G. pallidipes* pregnant female, young female, III, III. *G. brevipalpis* were very numerous. Catch ended 5.17 p.m.

Plate XII, fig. 4, shows a section of thicket in the rain forest. This photograph should be compared with Plate XII, fig. 3. In the type of thicket shown in the former photograph *G. pallidipes* do not flourish, but in the deciduous thicket shown in the latter they are very numerous. Plate XII, fig. 6, shows a section of the rain forest on the bank of the Ultra Juba.

The reconnaisance of the forest was made by car and the suggestion that many of the *pallidipes* captured may have been brought into the forest on the car cannot be lightly dismissed. It is thought that the forest is not the true habitat of *G. pallidipes*, but that a small population, introduced largely on cars, natives and game, is able to maintain itself. The forest is undoubtedly the true home of *G. brevipalpis*, for this species is found there in very great density.

An early morning catch was made, first in the edge of the Mansur forest on the west bank of the Ultra Juba, and later in the forest itself. Time 7.40 a.m. Temperature 78·0°F (25·6°C.). Sun bright, cloud 2, wind 2. Relative humidity 86 per cent. Catch on the edge of the forest : III, I, III, F4, young female, III, III, III, IV, III, III, III. Two male *G. brevipalpis* were taken. Catch ended 8.00 a.m. During the catch in the forest no *G. pallidipes* were seen but *G. brevipalpis* were present in great density. The presence of a fungus on the abdomen of the tsetse captured in the forest, similar to a pathogenic fungus known to exist in certain of the tsetse belts of Tanganyika, was noted.

An area of deciduous bush situated to the west of the Mansur forest was examined for tsetse. No fly were found in the area. Cattle were grazing the scanty grass of the locality at the time and they are said to remain in the vicinity all through the year. The bush was composed of small isolated thickets formed, in many cases, round single large trees, such as *Euphorbia candelabra* and *Acacia* sp. The species present were those already noted as being frequent in the dry areas remote from the Uebi Scebeli. *Terminalia Howtii* and *Combretum parvifolium* were also noted.

Reconnaisance at Ionte, Lower Juba.

Ionte is situated on the right bank of the River Juba, in the tidal section, a few miles to the north of the port of Chisimaio.

The marginal vegetation of this area was inspected and found to be free from tsetse, although fly, almost certainly *G. pallidipes*, infest the area in the wet season. *Hyphaena benadirensis* is very frequent, indeed large areas are wooded almost entirely with this species. Native cultivation is to be found along the banks of the river, although not to the extent noticed up-stream.

It is much regretted that time did not permit of further investigation, for a survey to ascertain the permanent habitat of the fly in this section of the river would have been of the greatest interest.

Conclusions.

1. The only species of tsetse to be found on the Uebi Scebeli is *Glossina pallidipes*, which concentrates in confined areas during the dry season. The fly increases in numbers in the wet season and spreads over the surrounding country to a maximum depth of 6 miles (10 kilometres).

2. The presence of deciduous thicket seems an essential constituent of the vegetation forming the true habitat and breeding-place of *G. pallidipes*, and high humidity and shade are essential in the areas over which the fly spreads in the wet season, it being capable of spreading through inhabited and cultivated areas during the wet season.

3. *G. pallidipes* is not able to maintain itself permanently under conditions of comparatively low temperature and high humidity in vegetation, of which the dominants are *Acacia arabica* and *A. Benthamii*, in the absence of deciduous thicket types.

4. Breeding is confined to areas of deciduous thicket, preference being shown for horizontal growing trees and for logs rather than for the bases of thicket types.

5. *G. pallidipes* is capable of being carried considerable distances by natives bearing loads.

6. *G. pallidipes*, *G. brevipalpis* and *G. austeni* are found on the River Juba.

7. In the Juba area *G. pallidipes* flourishes in deciduous thickets, while *G. brevipalpis* is found in great density in the rain forests, in which *G. austeni* is also encountered.

8. A fungus pathogenic to tsetse is present in the Alessandra fly area.

Note.—It will have been noted that conclusions regarding the wet season spread of *G. pallidipes* through the Genale farming area have been formed from deduction and not from observation.

An investigation conducted during the wet season would enable a check to be made on the conclusions formed and would also enable much information to be gained regarding the mechanism and the intensity of the wet season penetration.

Distribution of Species.

(*a*) Uebi Scebeli :—*Glossina pallidipes* only.

(*b*) River Juba :—

Locality	*Species*
Madoca	P.
Uagade	P.
Banta	P.
Bilai Uen	P.
Mallim Uen	P.
Scingani	P. A.
Mfudo	P. A.
Bulo Maionda	P. A.
Malenda	P. A.
Dugiuma	P. A.
Scionda	P. A.
Mololo	P.
Ghendfull	P. A.
Anole	P.
Barachi Magindo	P.
Sogido	P. B.
Manane	P.
Tarba	P.
Hurufle	P. A.
Daarta	P. A.
Duchia Mado	P.
Osman Mote	P.
Fanole	P.
Goriole	P.
Capinga	P.
Mansur	P. B.
Cumbarera	P.
Mansur	P. B.
Alessandra	P. B. A.

Note.—P indicates *G. pallidipes.*
B ,, *G. brevipalpis.*
A ,, *G. austeni.*

The species and the localities where they were taken were determined from specimens stored in the Sierovaccinogeno Institute, Merca. It has not been possible to place the localities in order relative to their position on the river.

Acknowledgments.

Grateful acknowledgment is made to the Government of Italian Somaliland for permission to carry out this investigation and their kindness in providing motor transport and camp equipment, as well as for arranging for the invaluable assistance received from members of the Sierovaccinogeno Institute.

To Dr. Falcone, Director, and Capt. Riva, Assistant Director, the warmest thanks are due for ready help and invaluable advice as well as for the memory of many pleasant hours spent in their company, both in the field and at the Institute.

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To Dr. Scales, Medical Officer, Genale, and to Dr. cav. Carlo Costa, Resident, Gelib, a debt of gratitude is acknowledged for their kindness and hospitality.

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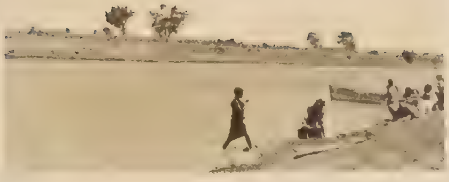
Acknowledgment is made to members of the Staff of the Royal Botanic Gardens, Kew, for identifying specimens of plants collected during the investigation.

References.

CROVERI, P. (1919). Osservazioni sulla biologia della *Glossina pallidipes* della Somalia Italiana e sulla trasmissione agli animali domestici della Tripanosi detta "Ghendi."—Ann. d'Igiene, **7,** p. 448.

JACKSON, C. H. N. (1933). The causes and implications of hunger in tsetse-flies. —Bull. Ent. Res. **24,** p. 443.

VICARS-HARRIS, N. H. (1934). Notes on meteorological records. Departmental minute, 2nd Nov., 1934.



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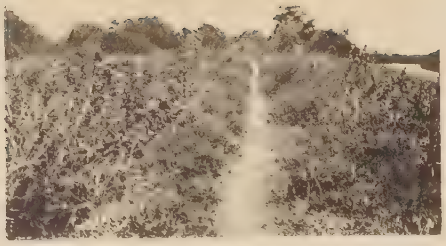

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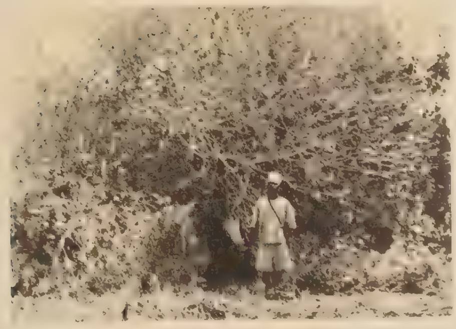

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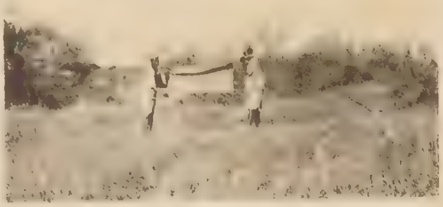

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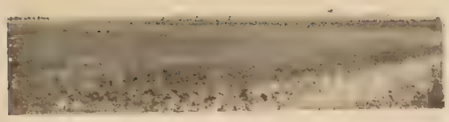

Fig. 5.

Fig. 6.

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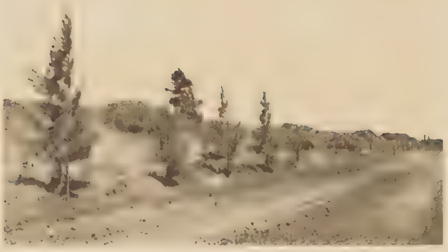
SCENES IN ITALIAN SOMALILAND.

Fig. 1.



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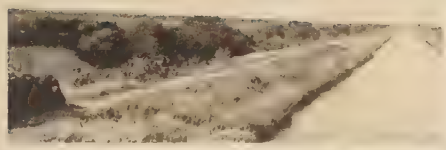

Fig. 3.

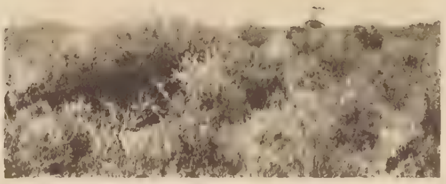

Fig. 4.

Fig. 5.

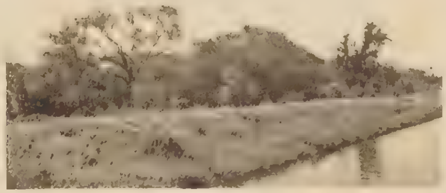

Fig. 6.

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PLATE XII.

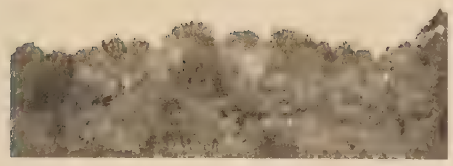

Fig. 1.

Fig. 2

Fig. 3.

Fig. 4.

Fig. 5.

Fig. 6.

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SCENES IN ITALIAN SOMALILAND.

ON THE BIOLOGY OF *EMPHYTUS CINCTUS*, L., AND *BLENNOCAMPA WALDHEIMI*, GIMM.* (*HYM*, SYMPHYTA).

By Herbert W. Miles, D.Sc., Ph.D.,
Department of Zoology, the Victoria University of Manchester.

(Plates XIII & XIV.)

In the course of investigations on sawflies of economic importance, *Emphytus cinctus*, L., and *Blennocampa waldheimi*, Gimm., have been found causing injury to Rosaceae. *Emphytus cinctus* has been transported from country to country with nursery stock[3] so that it is now a cosmopolitan species infesting strawberries and roses, and *Blennocampa waldheimi* is common and widely distributed over Europe[5], and is likely to prove of increasing importance in Britain as commercial strawberry cultivation extends and develops.

Emphytus cinctus, L.

Emphytus cinctus is one of the best known members of the genus *Emphytus*, Klug. It is common in Britain and is associated with Rosaceae ; and the frequent records of injury to foliage of *Rosa* and *Fragaria* by the larvae render the insects of some economic importance. Perkins[8] records the species as common in Devonshire. The writer has taken it on rose and strawberry in Lancashire and Cheshire, and has received it from Kent (W. E. Shewell Cooper), Hampshire and Berkshire (W. E. H. Hodson) where the larvae were feeding on strawberry. Theobald[10] records *E. cinctus* from raspberry (*Rubus idaeus*) in Herefordshire.

Description of Adults.

The sawflies are restless insects, exceedingly active in bright sunlight, strong fliers and difficult to capture. They are mainly black, but females have a conspicuous narrow white or cream-coloured transverse band along the anterior half of the fifth tergum. The head is black ; the antennae have nine segments ; the clypeus is deeply excised, and the eyes are distant from the bases of the mandibles. The thorax is black, but in both sexes the tegulae are margined with white. The legs are black with extensive light reddish yellow areas, and the tarsal claws are bifid. The fore and middle legs have the apices of the femora yellowish, and the tibiae and tarsi are reddish yellow, the hind legs have the trochanter conspicuously pale, the femur black and the tibia reddish or reddish yellow. The cerci are cylindrical with the apices rounded, and in females the saw-sheath is prominent.

The wings have a light yellowish tinge ; the veins are dark brown, and the stigma is dark brown with a narrow yellow band at the base. In the fore wing the radial cross-vein is present, but the radio-medial cross-vein is absent and cell R_5 is long and narrow ; the vein M_4 and Cu_1 arises at a point a third of the distance along the base of cell M_4, and A_2 passes obliquely towards A_3. In the hind wing the vein M_2 is missing and the medial cross-vein passes towards the anal margin of the wing†. The insects are 7–10 mm. long and have a wing expanse of 12–14 mm. (Plate XIII, fig. 1.)

[* =*B. geniculata*, auct., *B. confusa*, Kon., *B. puncticeps*, Kon., *B. subcana*, Zadd.—R. B. Benson.]

†Veins and cells named according to MacGillivray[6].

Oviposition and Eggs.

Cameron[1] and Theobald[10] have recorded that eggs are laid on the underside of leaves of rose, strawberry and raspberry. The eggs (Plate XIII, fig. 2) are large and inserted in roughly pocket-shaped incisions between the lower epidermis and the mesophyll of the leaf. Usually only one or two eggs are found on a leaf, but sometimes three or four occur together. On one occasion, in a Cheshire garden in May 1935, the writer found eight eggs on a single rose leaflet.

When first laid the eggs are rather flat and inconspicuous, but during incubation they swell, and after about a week they are visible on the upper surface as circular bulges and are readily seen on the lower surface (Plate XIII, fig. 2). For eggs under observation in May and early June the period of incubation was 12–14 days. Young larvae escape on to the lower leaf surface through an almost circular opening in the chorion and enclosing leaf epidermis.

The Larval Stage.

At eclosion the larva of *E. cinctus* is about 3 mm. long, which is comparatively large for a sawfly larva but consistent with the size of the egg. The head is dark and the body slender and tapering, greyish at first but greenish after feeding begins, and finely and evenly annulated. After hatching the larva (Plate XIII, fig. 3) bites into the lower surface of the leaf and eats out small circular or irregular areas without breaking through the upper epidermis, a habit common among other sawflies, notably *Cladius* spp. and *Endelomyia aethiops*, F., infesting the same host-plants.

In the second instar the head is light brown with the ocelli dark and conspicuous ; the dorsal surface of the body is dark green and the ventral surface, legs and prolegs are pale. At this stage the larvae begin to eat holes in the leaves of the host-plant. Larvae in the third instar resemble those of the second in appearance and feeding habits, but a few inconspicuous short, pale setae are visible on certain annulets and the head has a dark brown area on the vertex.

During the feeding instars the larvae feed voraciously and eat out large irregular areas from the leaves, and at times rest motionless for long periods with the tip of the body in a slightly curled position (Plate XIII, fig. 4). When disturbed they curl up tightly and fall from the plants, and may wander some distance before regaining the host-plant. Among strawberry plants where the foliage is dense the injury may be readily apparent, but the larval habit of falling when disturbed makes it difficult to find the insects. On roses the larvae are usually found singly curled up on the underside of a leaf, often at some distance from leaves showing signs of injury.

In the fifth instar the larvae are about 12 mm. long. The head is light yellowish brown with a dark area on the vertex extending forward along the epicranial suture and an obscure brownish area behind each ocellus. The ocelli are small and set in narrow dark circles with the colour diffused at the edges. The antennae are prominent and have five segments ; the frons is light yellowish brown, the clypeus rather paler than the frons, and the labrum usually brownish and shallowly emarginate. The mandibles are dark brown and heavily sclerotised ; the maxillae and labium are fleshy and prominent ; the maxillary palpi have four segments and the labial palpi have three. The body is velvety greyish green dorsally and translucent pale or yellowish green ventrally, and finely and evenly annulated. The legs are pale with the tarsal claws yellowish or brown, and the prolegs, which, as in other Selandriini, occur on segments 5–11 and on 13, are the same colour as the lower surface of the body. The caudal segment bears no pseudocerci but has a few short yellowish setae on the suranal and subanal lobes. The annulation gives the larvae a characteristically smooth appearance, and is constant for segments 5–11. Text-figure 1 shows the arrangement of the annulets on segment 6. The segment is divided into six annulets, A, B, C_1, C_2, C_3, and D, and short, blunt, pale setae occur on A, B and

C_2. The spiracle which lies below annulet B is inconspicuous; the alar area bears 2–3 short setae and the epipleurites may bear 1–2 small setae.

Males of *Emphytus cinctus* have six larval instars and females have seven. In the final larval stage no feeding takes place, but shortly after ecdysis the larvae leave the host-plants for sites suitable for hibernation and pupation.

Growth and development were observed in a batch of 10 larvae produced parthenogenetically. The larval feeding stages lasted 21–24 days, and the average growth ratio, calculated from the width of the frons in successive instars, was 1·26.

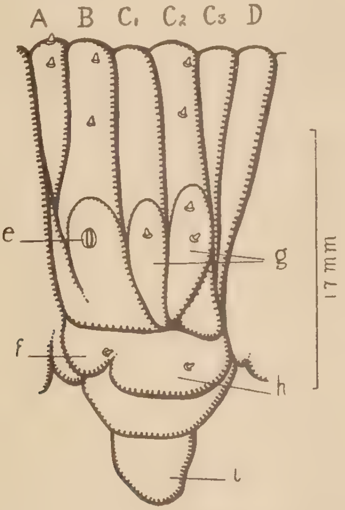

Fig. 1. *Emphytus cinctus*, L., larva; 6th body segment in profile to show arrangement of the annulets: *e*, spiracle; *f*, pre-epipleurite; *g*, alar area; *h*, post-epipleurite; *i*, proleg.

Pupal Stage.

When ready to pupate larvae of *E. cinctus* tunnel into pithy stems of herbaceous plants, snags left on roses after pruning, bases of old raspberry canes, and into dead or decaying wood. They usually penetrate to some depth and close the tunnels behind them with excavated fragments. Towards the end of the tunnel the fragments are tightly packed and bound together with saliva so as to seal in the larva. Pupation takes place in a thin, delicate, semi-transparent cocoon at the terminus of the tunnel. The summer generation of larvae usually spend 2–3 weeks in the cocoon before adults emerge, but some individuals may spend up to six weeks in the cocoon. The adult escapes through a circular hole at or near the entrance hole made by the larva.

The Annual Cycle and Parthenogenesis.

Emphytus cinctus is bivoltine in Britain. Adults occur normally in May and again in July, but laggards may be present during June and August. Larvae may be found on *Rosa* and *Fragaria* from early June until September. As noted by Enslin[4] the species has arrhenotokous parthenogenesis.

Blennocampa waldheimi, Gimm.

Blennocampa waldheimi has been recorded in Britain by Cameron[2], Perkins[9] and Miles[7]. On the continent of Europe[11] it is recorded as feeding on *Fragaria, Geum urbanum* and *Rubus* spp., and in Britain the larvae are frequently found on *Spiraea* *ulmaria*. The writer has taken larvae on spiraea in Lancashire and Cheshire and in the gardens of Farnham House Laboratory, Berkshire. In 1934 larvae were sent to the writer by Dr. C. L. Walton who found them causing considerable injury to the foliage of strawberry in the Cheddar Valley, Somerset. The observations on the life-history and immature stages were made on the progeny of these larvae.

Description of Adults.

B. waldheimi is a shining black sawfly, 6–7 mm. long, with a plump oval body and slightly yellowish wings. The head is clothed with fine pale pubescence; the antennae have nine segments, the third segment being rather less than 1½ times the length of the fourth. The eyes are situated so low on the sides of the head that they are practically contiguous with the bases of the mandibles. The legs are shining black with the tips of the femora white, and the fore and middle pairs of legs usually have white or cream areas on the basal portions of the tibiae and tarsi. The female (Plate XIV, fig. 1) has the saw-sheath conspicuous and characteristically protruded.

The wings are tinged with pale yellow, and the stigma and veins are dark brown or almost black. In the fore wing the radial cross-vein and R_5 are opposite, and the radio-medial cross-vein and R_4 are also present. The medio-cubital cross-vein and M_3 and $_4$ are almost parallel, and A_3 is short and not united with A_2. In the hind wing M_2 is usually missing and cell M_4 is open, but in some specimens M_2 is present.

Flight Period and Oviposition.

Adults may be found about strawberry plants towards the latter half of May and the first half of June. They are shy insects, and when disturbed they fall from the foliage with legs, wings and antennae folded close to the body. In dull weather they lie motionless for some little time, but on sunny days they fly again almost at once.

The eggs are laid in pocket-shaped incisions near the edges of the leaves, in the stipules, and occasionally in the young leaf-stalks. The position of the eggs in the leaf is shown in Plate XIV, fig. 3. The pubescence on the leaf-stalks and young leaves appears to afford the plant some protection from *B. waldheimi*, since females under observation repeatedly abandoned pubescent parts of the plant after attempting to lay eggs there. Where conditions are suitable several eggs occur close together.

At first the eggs are not easily seen, but they swell slightly during incubation and become noticeable in the tissue. In the laboratory the period of incubation was 13–16 days and eggs laid 25th–28th May hatched on ~~1st~~ June.

th June

The Larval Stage.

First Instar.—Newly hatched larvae measure about 2 mm. and are greyish white with the head smoky grey. After a day or two a pale pubescence becomes apparent on the body but is not conspicuous. The larvae are found on the lower surface of the leaves where they eat out small circular holes. The first stadium lasts 5–6 days and when ready to moult the larvae measure 4–5 mm.

Second Instar.—In the second instar the larva has a pale yellowish head with some brown about the apex of the frons, black ocelli and brown trophi. The body is pale green with conspicuous branched spines arising from small tubercles. The contents of the alimentary canal are visible as a dark band along the mid-dorsal line. The second stadium lasts 4–5 days, and towards the end of the stadium the larvae are 7–8 mm. long.

Third Instar.—Third instar larvae have the head pale yellowish brown, with the frons darker brown and the clypeus pale. The body is pale yellowish green, but appears dark dorsally owing to the presence of food in the digestive system, and the pale bifurcate spines are strongly developed and conspicuous. The larvae feed mainly on the under-sides of the leaves and eat out large irregular holes. The third stage lasts 4–6 days and the larvae attain a length of 11–12 mm.

Fourth Instar (Plate XIV, fig. 2).—In the fourth stage the larvae attain their maximum growth and measure up to 16 mm. The head is mainly light yellowish brown and clothed with slender, pale yellowish setae. The frons is dark brown at the apex and pale along the clypeal margin, and the labrum is dark brown and deeply and narrowly excised. The ocelli are small and set in narrow black ocellar circles; the antennae are slender and projecting and have five segments. The mandibles are brown and the maxillae and labium pale yellow; the maxillae are fleshy and the maxillary palpi are slender and four-segmented; the labium protrudes and the labial palpi are elongate and three-segmented.

The body is pale yellowish green ventrally and darker greyish green dorsally; the spiracular line is not pronounced, and the spiracles are small, pale and inconspicuous. The legs are long and well developed; the tibiae are fleshy and near the tip of each is a bilobed protuberance, the anterior lobe of which is larger and subacuminate and the posterior lobe smaller and rounded. The tarsal claws are yellow or brown, long, slender, and sharply curved. Prolegs occur on segments 5–11 and on 13. The caudal segment has no pseudocerci and bears simple setae on the suranal and subanal lobes. The body is clothed with a characteristic armature of long, branched and barbed spines. Those on the dorsal part of the prothorax are 5 or 4-branched and directed obliquely forwards over the head; most of those on the remainder of the body are bifurcate, but on the sides there are some simple spines and on the final tergum there are usually four simple spines directed backwards.

The annulation of the segments is obscured by the thick covering of spines, but on segments 5–11 the annulation and arrangement of spines appears to be constant.

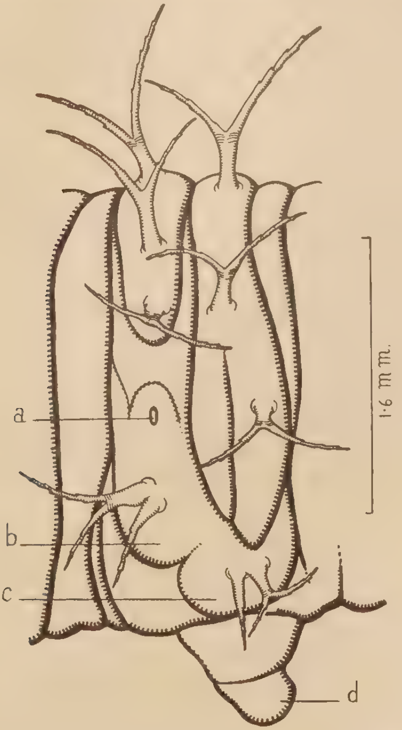

Fig. 2. *Blennocampa waldheimi*, Gimm., larva; 6th body segment in profile to show arrangement of the annulets and the distribution of the spines: *a*, spiracle; *b*, pre-epipleurite; *c*, post-epipleurite; *d*, proleg.

Text-fig. 2 shows segment 6 in profile. There are four annulets, A, B, C and D; A and D are rather narrow and devoid of spines, and B and C each bear a row of three bifurcate spines arranged alternately and pointing in all directions. The alar area is bare, and the epipleurites bear one bifurcated and one simple spine.

After feeding for 6–8 days the fourth instar larvae rest motionless on the undersides of the leaves for some days. During this quiescent period there is no feeding and food in the alimentary system is completely digested. The larvae moult for the fourth time after spending 13–18 days in the fourth instar.

Fifth Instar.—Larvae in the fifth instar are dull greyish green and devoid of the conspicuous armature of spines that characterized the previous instars. No feeding takes place during this stage, but shortly after ecdysis the larvae enter the soil to construct their cocoons. Six larvae were bred parthenogenetically from one female and were reared on strawberry; the larval feeding stages occupied 32–38 days. Growth was fairly regular during the feeding stages, and the average growth ratio, calculated from the width of the frons in successive stages, was 1·26.

The Cocoon and Pupation.

Larvae in the prepupal stage construct rough, oval, dark brown, parchment-like cocoons 8–10 mm. in length, at a depth of 2–3 inches in the soil. The larvae remain in the cocoons from July until the following spring when pupation takes place.

Annual Cycle and Parthenogenesis.

Blennocampa waldheimi is univoltine. Adults begin to emerge during May and larvae may be found on the host-plants during June and July. The larvae complete their development from the beginning of July onwards and enter the soil, where they construct cocoons in which they pass the winter. Parthenogenesis occurs and is thelytokous or female-producing.

Economic Importance.

Though *B. waldheimi* occurs most commonly on *Spiraea* spp. growing in damp or marshy situations, it is also found on cultivated species of *Geum* and *Fragaria*. The discovery of considerable numbers of larvae feeding on strawberry in commercial plantations in the Cheddar Valley, Somerset, and the freedom with which insects under observation laid eggs on strawberry plants, suggests that where the wild host is destroyed through draining, clearing or reclaiming operations, *B. waldheimi* may assume considerable economic importance.

I am indebted to Dr. C. L. Walton for his interest in forwarding larvae of *Blennocampa waldheimi* from Somerset in 1934, and to Mr. Morris Cohen, M.Sc., for assistance with the preparation of the text-figures. I am grateful to Mr. R. B. Benson, M.A., for his kindness in examining the adult insects and confirming their identity, and for the trouble he has taken in working out the synonymy of *B. waldheimi*.

References.

[1] CAMERON. (1882). Monograph of British Phytophagous Hymenoptera, **1**, pp. 269–70.

[2] ———. *Ibid.*, pp. 238–9.

[3] CHITTENDEN. (1908). U.S. Dept. Agric., Circ. **105,** p. 10.

[4] ENSLIN. (1912–17). Die Tenthredinoidea Mitteleuropas, pp. 229–230.

[5] ——— *Ibid.*, pp. 295–6.

[6] MACGILLIVRAY. (1906). Proc. U.S. Nat. Museum, **29,** pp. 569–654.

[7] MILES. (1935). Lancs. Ches. Faunal Comm. Ann. Rep. **21.**
[8] PERKINS. (1929). Trans. Devon Ass. Sci., **61,** p. 291.
[9] ———. *Ibid.*, p. 296.
[10] THEOBALD. (1909). Insect Pests of Fruit, pp. 434–38.
[11] TULLGREN. (1905). Ent. Tidskr., p. 252.

EXPLANATION OF PLATE XIII.

Fig. 1. *Emphytus cinctus*, L., adult ♂.

2. Eggs of *E. cinctus* in lower surface of leaflet of rose.

3. 1st instar larva of *E. cinctus* on leaflet of rose. The egg site is visible towards the apex of the leaflet and the injury is typical of that caused by young larvae of *Emphytus*.

4. 5th instar larva of *E. cinctus* on a rose leaf which shows the type of injury caused by the older larvae of *Emphytus*.

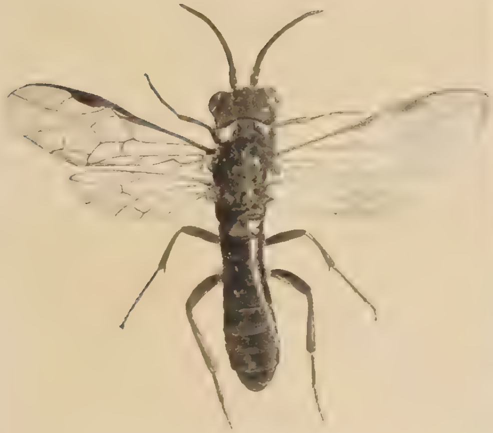

Fig. 1

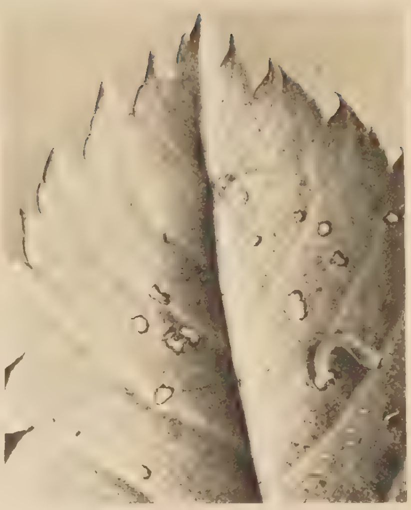

Fig. 3.

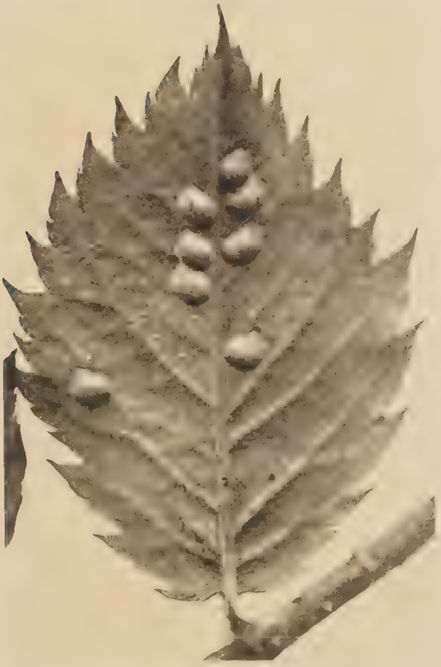

Fig. 2.

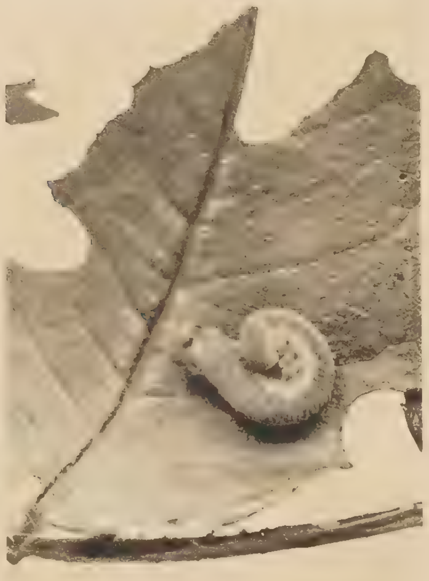

Fig. 4.

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STAGES OF *EMPHYTUS CINCTUS*, L.

EXPLANATION OF PLATE XIV.

Fig. 1. Adult ♀ of *Blennocampa waldheimi*, Gimm., showing the form of the antennae, the wing venation and the protruding saw-sheath.

2. 4th instar larva of *B. waldheimi* on strawberry leaf.

3. Eggs of *B. waldheimi* in strawberry leaf.

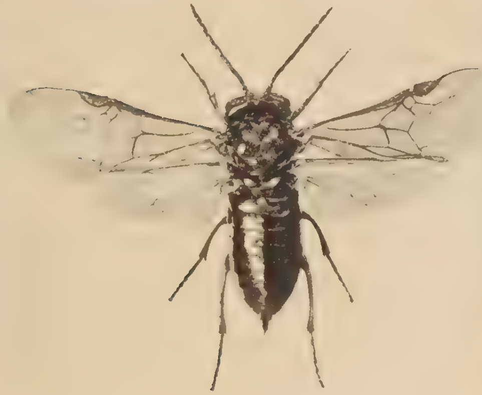

Fig. 1.

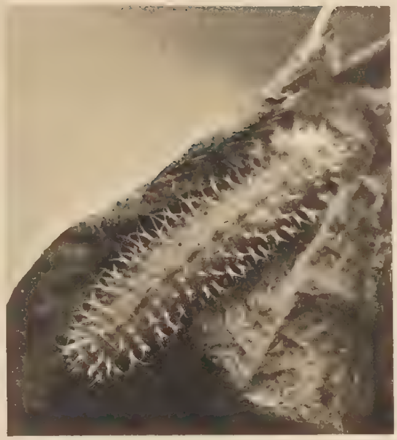

Fig. 2.

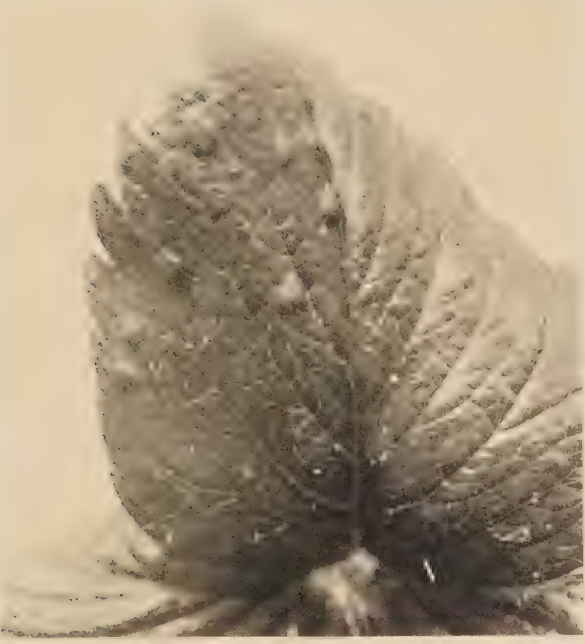

Fig. 3.

John Bale [illegible] nielsson, Ltd London

STAGES OF *BLENNOCAMPA WALDHEIMI*, GIMM.

THE PARASITES OF THE COFFEE LEAF-MINERS (LEUCOPTERA SPP.) IN AFRICA.

By Ch. Ferrière, D.Sc.,

Imperial Institute of Entomology.

The coffee leaf-miners of the genus *Leucoptera*, Hübner, are serious pests of coffee wherever it is cultivated and they have often caused great anxiety to planters in many parts of the world. *Leucoptera coffeella*, Guér., is known from the West Indies, Central and South America, Central Africa, Madagascar, Réunion and Ceylon. Another species, *L. daricella*, Meyr., seems to be responsible for still more damage in Africa.

Although the former has been mentioned or studied by several authors, as far back as 1842, when it was first described by Guérin-Méneville from the West Indies under the name of *Elachista cofeella*, very little is still known about its parasites.

The first to mention parasites of *Leucoptera* in America was B. P. Mann, who studied the bionomics of the "white coffee leaf-miner" in Brazil in 1872. He described two parasites, one feeding upon the larva, *Eulophus cemiostomatis*, Mann, the second hatching from the pupa, named *Bracon letifer*, Mann, but said to be related to *Exothecus exsertor*. Later Giard (1898) and Box (1923) refer to this species as *Exothecus letifer*, Mann, but we have no knowledge that either of these parasites has been found or recognised again.

Hooker (1912) and van Zwaluwenburg (1914), studying the biology of *Leucoptera coffeella* in Porto Rico, recorded two other parasites, both Chalcids, *Chrysocharis livida*, Ashm., and *Zagrammosoma multilineatum*, Ashm., the former being specially abundant. These two species are also mentioned from Porto Rico by Wolcott (1921) and have been found in Venezuela by Box (1927). In Brazil R. v. Ihering (1914) described three new Chalcid parasites of *Leucoptera*, which he named *Closterocerus coffeellae*, *Proacrias coffeae* and *Eulophus* sp. Lastly, in Cuba, Bruner (1929) discovered four other Chalcids parasitising *L. coffeella*, viz. *Elachertus* sp., the most common, *Horismenus cupreus*, Ashm., *Closterocerus cinctipennis*, Ashm., and *Zagrammosoma mutilineatum*, Ashm.

From Africa the first record of parasites came from the Isle of Réunion, whence Giard (1898) received two species, a *Eulophus* and an *Apanteles*. In 1902 he adds only names to these species, without descriptions, saying (in translation): "It (*Cemiostoma cofeella*) has been introduced into Réunion, where it is not so noxious, owing to the presence of two Hymenoptera: *Eulophus borboricus*, Giard, and *Apanteles bordagei*, Giard, which I have made known a few years ago. These parasites lived probably on other Microlepidoptera, but are now well adapted to the *Cemiostoma*, the damages of which have been reduced almost to nothing." Bordage (1913) mentions again these species from Réunion, without adding anything to Giard's notes. On the African continent Box (1923) reared three species of parasites in Kenya, "specimens of two of these species were submitted to Dr. J. Waterston, who has determined one of them as a Braconid of a genus allied to *Hormius* and the other as a Eulophid, *Atoposoma variegatum*, Masi, var. *afra*, Silvestri. The writer has reason to believe that the third species is also a Eulophid of the genus *Chrysocharis*." During these last years, we described an *Elasmus leucopterae*, Ferr., in 1931, from a female received from Tanganyika; Mr. D. S. Wilkinson (1934) gave a complete redescription of *Apanteles bordagei*, Giard, from a series of specimens from Kenya and Tanganyika, and he has just described (1936) another Braconid, *Mirax leucopterae*, Wilk.

Thus, from the literature, 17 species of parasitic Hymenoptera are known to live on the coffee leaf-miner, either as primary or as secondary parasites :—

(1) In America : *Exothecus letifer*, Mann, *Elachertus* sp. (Bruner), *Zagrammosoma multilineatum*, Ashm., *Eulophus cemiostomatis*, Mann, *Eulophus* sp. (Ihering), *Horismenus cupreus*, Ashm., *Closterocerus cinctipennis*, Ashm., *Closterocerus coffeellae*, Iher., *Proacrias coffeae*, Iher., *Chrysocharis livida*, Ashm.

(2) In Africa : *Apanteles bordagei*, Giard, *Mirax leucopterae*, Wilk., *Hormius* sp. (Box), *Elasmus leucopterae*, Ferr., *Atoposoma variegatum* var. *afra*, Silv., *Eulophus borboricus*, Giard, *Chrysocharis* sp. (Box).

Since 1930 Mr. A. H. Ritchie has studied the parasites of *Leucoptera* in Tanganyika and has sent to the Imperial Institute of Entomology a large number of specimens. A few more specimens were obtained also from Kenya (Dr. R. H. LePelley), Uganda (Mr. H. Hargreaves) and Nyasaland (Mr. C. Smee). In this large material more than 20 different species could be found, but several of them have been left aside as having probably nothing to do with *Leucoptera*, some being known as parasites of Coccids, Diptera or eggs of other insects. We have retained 16 species, parasites or hyperparasites of *Leucoptera* in Central Africa, 2 Braconids, which have been made known by Mr. Wilkinson, and 14 Chalcids, which are studied or described in the following pages. These parasitic Hymenoptera are :—

BRACONIDAE ...	*Apanteles bordagei* Giard,
	Mirax leucopterae, Wilk.
PTEROMALIDAE ...	*Trigonogastra nigricola*, sp. n.
ELASMIDAE ...	*Elasmus leucopterae*, Ferr.
EULOPHIDAE ...	*Cirrospilus cinctiventris*, sp. n.
	Cirrospilus longifasciatus, sp. n.
	Atoposoma variegatum, Masi var. *afra*, Silv.
	Eulophus borboricus, Giard
	Sympiesis bukobensis, sp. n.
	Pleurotropis coffeicola, sp. n.
	Achrysocharella ritchiei, sp. n.
	Closterocerus africanus, Wat.
	Chrysocharis lepelleyi, sp. n.
	Teleopterus violaceus, sp. n.
	Derostenus coffeae, sp. n.
	Tetrastichodes leucopterae, sp. n.

Judging by the number of specimens of each species received here, the most important species seem to be : *Pleurotropis coffeicola*, 210 specimens from Tanganyika, Kenya and Uganda ; *Achrysocharella ritchiei*, 58 spec. from Tanganyika, Kenya and Nyasaland ; *Elasmus leucopterae*, 56 spec. from Tanganyika and Kenya ; *Apanteles bordagei*, 36 spec. from Tanganyika and Kenya ; *Atoposoma variegatum afra*, 34 spec. from Tanganyika, Kenya and Nyasaland.

This is confirmed by Mr. Ritchie's report for 1934, in which he says : " Parasites reared during this year's studies from *Leucoptera*-infested foliage have embraced the following : *Apanteles bordagei*, Giard, *Elasmus leucopterae*, Ferr., and *Pleurotropis* sp., *Chrysocharis* sp., *Atoposoma variegatum*, Masi var. *afra*, Silv. Of these the *Elasmus*, the *Pleurotropis* and the *Chrysocharis* have preponderated." The *Chrysocharis* mentioned here was later identified with the genus *Achrysocharella*.

Two species of *Leucoptera* are now known to be present on coffee in Africa, *L. coffeella*, Guér., and *L. daricella*, Meyr. According to Ritchie, *L. daricella* " amounted in plantations subject to a miner wave in 1934 to 87·5 per cent. of the *Leucoptera* population and in less affected plantations to 62 per cent." As all the Hymenoptera sent up to 1934 had been considered as parasites of *L. coffeella*, it is not known if some of the parasites attack one more than the other of these two species.

Fam. PTEROMALIDAE.
Subfam. SPHEGIGASTERINAE.

Trigonogastra nigricola, sp. n.

♀♂. Body black, with faint dark green reflection on face, propodeon and hind coxae ; antennae black, with the scape and the end of the pedicel yellowish ; legs orange-yellow, except the coxae which are concolorous with the body ; wings hyaline.

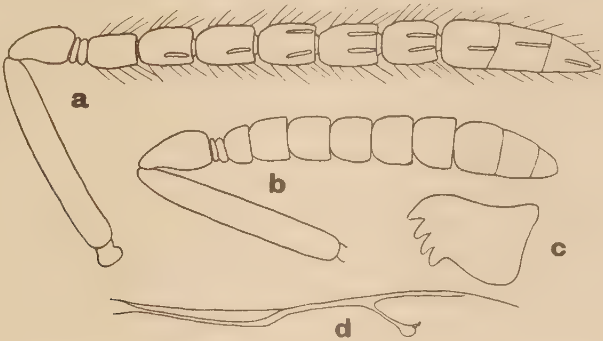

Fig. 1. *Trigonogastra nigricola*, sp. n. : **a**, antenna of ♂ ; **b**, antenna of ♀ ; **c**, mandible ; **d**, wing nervature.

♀. Head transverse, a little broader than the thorax, the occiput not margined ; vertex and frons finely reticulated. Ocelli forming a low triangle, the lateral ocelli nearer to the front ocellus than to the eye margin. Eyes oval, cheeks as long as the transverse breadth of an eye. Mandibles both with 4 teeth. Antennae inserted at the level of the base of the eyes, with 13 joints ; scape narrow and elongate, reaching almost the front ocellus ; pedicel about twice as long as broad ; 2 annelli, short and transverse ; 1st funicle joint shorter and narrower than the following, slightly broader than long ; the 5 following joints subequal in length, the 2nd funicle joint subquadrate, the 6th broader than long ; club with 3 joints, not broader than the funicle, and a little longer than the two preceding joints together.

Thorax finely reticulated, dull ; pronotum not transversely carinated ; mesonotum broader than long, the parapsidal furrows only visible in front ; scutellum with short black ciliae ; propodeon with the reticulation stronger than on the scutellum, but also dull ; middle of propodeum convex, with a rather strong nucha behind. Wings large, reaching beyond the tip of the abdomen ; marginal vein shorter than the submarginal, but as long as the postmarginal ; stigmal vein about as long as 3/5 of the length of the marginal ; discal ciliae short, from below the marginal vein to the tip ; base of wing glabrous, except an oblique line of ciliae below the end of the submarginal vein. Legs narrow ; hind coxae punctate.

Abdomen as broad and almost as long as the thorax, smooth and shining ; petiole finely rugulose, a little longer than broad, as long as the hind coxae ; 2nd segment strongly broadened behind ; 3rd with the sides subparallel, as long as the 2nd ; 4th short, transverse, but as broad as the 3rd ; the following very short and gradually narrower, the last small, triangular. Ovipositor scarcely protruding.

♂. Similar to the female. Antennae longer and more ciliate ; 1st funicle joint longer than broad, the 6th subquadrate ; club almost as long as the three preceding joints together. Abdomen shorter and narrower than the thorax, the petiole a little longer than the hind coxae, about 3 times as long as broad ; 2nd tergite triangular, large ; 3rd shorter than the 2nd, broader than long ; the following very short and partly hidden.

Length : ♀ 1·4–1·9 mm. ; ♂ 1·2–1·7 mm.

TANGANYIKA : Arusha, Burka Estate, vii.1932, 3 ♀ 5 ♂ " ex coffee leaf-miner " (*A. H. Ritchie*).

This is the first species of the genus known from Africa. Other species, in Ceylon and Australia, are parasites of Dipterous leaf-miners of the genus *Agromyza*.

Fam. ELASMIDAE.

Elasmus leucopterae, Ferr.

Ferrière, Bull. Ent. Res., **22,** 1931, p. 131.

The original description was made from a single female from Morogoro, Tanganyika. Since then we have received several other specimens and have now a series of 32 ♀ and 22 ♂ from the following localities :

KENYA COL. : Kiambu, 1932, 2 ♀ 1 ♂ " ex *Leucoptera coffeella*" (*Dr. R. LePelley*). TANGANYIKA : Arusha, Burka Est., vii.1932, 1 ♂ " ex coffee leaf-miner " ; Moschi, Kichoni Plant., xi.1934, 19 ♀ 12 ♂ " ex *Leucoptera coffeella*," 2 ♀ 1 ♂ " ex *Leucoptera* in *Oxyanthus speciosus*," 8 ♀ 5 ♂ " ex *Leucoptera* from *Cremaspora africana* " ; Uru Distr., Kilimandjaro, xii.1935, 2 ♂ " ex *Leucoptera* from *Coffea arabica* " ; Bukoba, Nyakato, vii.1935, 1 ♀ " ex *Leucoptera daricella* on *Pavetta ternifolia* " (*A. H. Ritchie*).

This species varies somewhat in size and coloration. The length of the body is : ♀ 1·4–2 mm., ♂ 0·8–1·4 mm. In the ♀ we may distinguish four different colour variations.

Var. 1.—Hind coxae mostly yellow, more or less black above ; femora yellow, with narrow black stripes above and below ; abdomen reddish on basal half below and with a marked reddish transverse stripe above.

Var. 2.—Hind coxae half black, half yellow ; femora yellow with broad black stripes above and below, the hind femora slightly brownish in the middle ; abdomen with only a faint transverse stripe above but also reddish below.

Var. 3.—Hind coxae black, yellow only at tip, less than 1/3 of the surface ; femora black or brown, yellow at base and at tip ; abdomen less markedly reddish below.

Var. 4.—Hind coxae entirely black ; hind femora black almost to the tip, more or less yellow at base ; abdomen black, slightly reddish only at base below.

The type is like var. 1, but in the material examined these four varieties appear in about equal numbers, with all forms of transitions between them.

The male is black with the coxae and the middle and hind femora almost entirely black or brown, and the tibiae yellow.

Fam. EULOPHIDAE.

Subfam. ELACHERTINAE.

Cirrospilus cinctiventris, sp. n.

♀♂. Body orange-yellow, with two black transverse stripes round the abdomen, one on the posterior half of the 3rd segment, the other on the 5th segment ; sheath of ovipositor black ; end and longitudinal furrows of the scutellum more or less marked with black lines, as are the hind and lateral margins and the median carina of the propodeon. In the male the 1st transverse stripe on the abdomen is narrower and the propodeon is brownish in the middle. Antennae yellow, club brown ; legs orange-yellow, coxae and trochanters light yellow. Wings slightly infuscate below the marginal vein.

♀. Head very transverse, seen from in front a little broader than high ; posterior ocelli twice as far from each other as from the eye margins ; cheeks a little longer than half the longitudinal diameter of an eye. Antennae with 9 joints; scape narrow, reaching to the front ocellus; pedicel elongate, almost 3 times as long as broad; 2 small annelli; 1st funicle joint as long as the pedicel, 2nd shorter, but still about 1½ times longer than broad; club with 3 joints, as long as the funicle, the 3rd joint triangular with a small spur at tip.

Pronotum rather large, with a row of six ciliae along the hind margin; mesonotum finely reticulated, but shining, with the parapsidal furrows well marked and two rows of three ciliae on the sides of the median lobe; scutellum more finely reticulated, almost smooth, rounded, with conspicuous longitudinal furrows; propodeon smooth, with a median carina. Wings large, reaching much beyond the end of the abdomen; marginal vein as long as the sub-marginal, about three times as long as the stigmal and postmarginal veins, which are subequal in length; marginal ciliae short.

Abdomen oval, as broad and as long as the thorax; petiole broader than long; ovipositor scarcely protruding.

♂. Similar to the female, but smaller. Antennae shorter, the two funicle joints shorter than the pedicel, the 1st slightly longer than the 2nd; club with 3 joints, narrow, longer than the funicle. Abdomen as long as but narrower than the thorax.

Length: ♀ 1·2–1·5 mm.; ♂ 0·8–0·9 mm.

TANGANYIKA: Bukoba, 19.vii.1935, 6 ♀ "ex coffee leaf-miner"; Bukoba, Nyakato, 24.viii.1935, 11 ♀ 3 ♂ "ex *Leucoptera daricella* on *Pavetta ternifolia*"; Bukoba, 14.ix.1935, 1 ♀ "ex moth leaf-miner of *Bridelia micrantha*" (*A. H. Ritchie*).

Cirrospilus longifasciatus, sp. n.

♀. Body yellow; head with the frons and occiput black, thorax with a broad longitudinal stripe, greenish black, extending along the middle of the pronotum, mesonotum, scutellum and postscutellum, a little narrowed near the hind margin of the pronotum; propodeon black above; mesosternum brown; abdomen with the sides yellow, otherwise brown above and below. Antennae with scape and pedicel black above, yellow below, the rest of the flagellum brown. Legs entirely yellow. Wings hyaline.

Head transverse, seen from in front rounded, with the eyes oval and the cheeks as long as half the length of the eyes. Antennae with the scape short, slightly broadened, reaching to the front ocellus; pedicel not much longer than broad; two transverse annelli; the 2 funicle joints subequal in length, longer than the pedicel about 1·5 times as long as broad; club with 3 joints, a little shorter than the funicle, the 3rd joint terminating in a small spur.

Thorax finely reticulated, shining; propodeon more rugulose; pronotum conical; parapsidal furrows well marked; longitudinal furrows on the scutellum fine but conspicuous; propodeon with a median carina. Wings large; marginal vein as long as the submarginal; stigmal vein narrow but relatively long, about as long as 1/3 of the marginal; postmarginal vein as long as the stigmal; marginal ciliae short.

Abdomen oval elongate, as long as head and thorax together; petiole short, transverse; ovipositor slightly protruding.

Length: 1·5–1·6 mm.

TANGANYIKA: Arusha, Vickers Estate, vii.1932, 2 ♀ "ex coffee leaf-miner" (*A. H. Ritchie*).

Not a single species of the genus *Cirrospilus*, Westw., has previously been described from Africa. These two species are easily recognisable by the yellow coloration of the body; *C. cinctiventris* with two black rings on the abdomen, *C. longifasciatus* with a broad longitudinal stripe along the back of the thorax, and the abdomen brown. The first seems to be a common parasite of *Leucoptera* in at least a part of Tanganyika.

Atoposoma variegatum, Masi, var. **afra,** Silv.

Silvestri, Boll. Lab. Zool. gen. e. agr. Portici, **9,** 1914, p. 208.

Many specimens agreeing with Silvestri's description and drawing have been received from the following localities :

NYASALAND : Ncheu, 13 ♀ 6 ♂, vii.1929 (*C. Smee*). KENYA COL. : Kiambu, 3 ♀ 1 ♂, 1932 (*Dr. R. LePelley*). TANGANYIKA : Arusha, 5 ♀ 4 ♂, vii.1932 ; Moshi, Kichoni, 2 ♀, xi.1934 (*A. H. Ritchie*). All are labelled either "ex *Leucoptera coffeella*" or "ex coffee leaf-miner."

Silvestri's specimens had been obtained mostly from larvae of *Dacus oleae*, but also from the mining larvae of *Oecophyllembius inferior*, Silv. The extension and breadth of the black lines on the thorax and abdomen may vary somewhat, but they are never very broad.

Subfam. EULOPHINAE.

Eulophus borboricus, Giard.

Eulophus sp., Giard, Bull. Soc. Ent. Fr., 1898, p. 201.

Eulophus borboricus, Giard, Bull. Sect. Agric. Coloniale, 1, 1901–02, Paris 1903, Notes et Mémoires, p. 22.

This species has never been adequately described, and from notes received from Mr. L. Berland, the type is not in the Museum in Paris and is probably lost. It is therefore impossible to know exactly what this species is.

In 1898 Giard wrote about the parasites found in Réunion : "One is a *Eulophus* very different from *E. cemiostomatis* (from Brazil). This last has an aeneous metallic coloration, whereas the species from Réunion is black with a yellow spot at base of abdomen." Among the material received we found two species which are black with a yellow spot at the base of the abdomen, but only one is a *Eulophus* ; the other belongs to the TETRASTICHINAE and we do not think that it could have been confused, even by Giard, with a Eulophine ; it is described below under the name of *Tetrastichodes leucopterae*, sp. n. We believe, therefore, that the *Eulophus* (black with yellow base of abdomen) which we have is really the *Eulophus borboricus* of Giard. Unfortunately we received only one female of that species, with the antennae broken, which is described here below.

♀. Body black, abdomen with a broad yellow spot extending on the 2nd and 3rd segments above and below, but leaving the sides of these segments narrowly black. Scape, mandibles and legs yellow, only the coxae black.

Head transverse, finely shagreened ; ocelli forming a low triangle. Antennae inserted a little above the lowest level of the eyes, but broken ; the scapes (which alone are present) narrow, reaching to the front ocellus. Thorax entirely reticulated, more finely on the scutellum and the propodeon than on the mesonotum and pronotum. Parapsidal furrows only in front, short. Propodeon rather long, with a median carina and lateral sulci. Wings large, reaching beyond the end of the abdomen ; marginal vein a little longer than the submarginal and about 5 times as long as the stigmal vein ; postmarginal vein twice as long as the stigmal. Abdomen shortly petiolated, oval, as long and as broad as the thorax. Ovipositor not protruding.

Length 2·2 mm.

TANGANYIKA : Moshi, Xeno Plant., 29.x.1934, 1 ♀ "ex coffee leaf-miner" (*A. H. Ritchie*).

Sympiesis bukobensis, sp. n.

♀♂. Dark green, with bronze reflections on thorax and end of abdomen, and violaceous on head above the antennae. Antennae black, scape and pedicel with metallic reflections. Legs greenish black, the knees, end of tibiae narrowly and the three first joints of the tarsi, yellowish. Wings, hyaline.

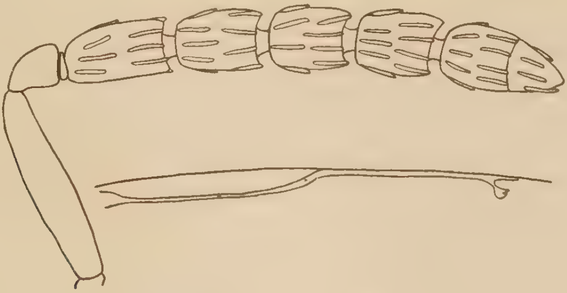

Fig. 2. *Sympiesis bukobensis*, sp. n., ♀ ; antenna and wing nervature.

♀. Head transverse, temples very narrow, eyes slightly diverging below, cheeks very oblique and short ; frons concave between antennae and ocelli. Antennae with 9 joints ; scape narrow, reaching scarcely to the front ocellus ; pedicel not longer than broad ; one small transverse annellus ; funicle with 4 joints, the 1st the longest, about twice as long as broad, 2nd shorter, about 1·5 times as long as broad, 3rd and 4th subquadrate ; club with 2 joints, 1·5 times as long as the 4th funicle joint.

Thorax finely reticulated, the reticulation smaller and weaker on the scutellum than on the mesonotum ; parapsidal furrows only in front ; postscutellum partly hidden below the end of the scutellum ; propodeon smooth, with a median carina ; mesopleurae closely and finely reticulated. Wings large ; marginal vein almost as long as the costal cell and about 9 times as long as the stigmal vein ; postmarginal vein slightly longer than the stigmal.

Abdomen narrower and scarcely longer than the thorax, smooth and shining, finely shagreened at the end, the sides parallel, then converging after the 5th segment ; the segments subequal in length. Ovipositor slightly protruding.

♂. Quite similar to the female. Antennae without branches, the scape relatively narrower and a little longer, the 4 funicle joints somewhat longer than broad, the 1st joint the longest. Abdomen narrower and shorter than the thorax.

Length : ♀ 1·9–2 mm. ; ♂ 1·6 mm.

Tanganyika : Bukoba, 19.vii.1935, 5 ♀ 2 ♂ " ex coffee leaf-miner " (*A. H. Ritchie*).

Subfam. Entedoninae.

√ **Pleurotropis coffeicola,** sp. n.

♀♂. Bluish green, with violaceous reflections on the sides of the thorax and the end of the abdomen ; propodeon and the base of the abdomen more shining green or blue ; antennae and legs entirely metallic green, except the tarsi, which are white with the last joint black.

♀. Head transverse, a little broader than the thorax, margined behind, with the temples very narrow behind the eyes. Vertex broad, finely shagreened ; ocelli forming a regular triangle, the lateral ocelli as far distant from the eye margins as their own diameter ; the sides of the eyes, behind the ocelli, smooth and shining ; eyes large, subparallel in front ; cheeks short. Mandibles with two small, regular teeth. Antennae inserted a little below the lowest level of the eyes ; scape narrow, not reaching to the front ocellus ; pedicel about 1·5 times as long as broad ; one small transverse, annellus ; 1st funicle joint longer and broader than the pedicel, but also about 1·5 times as long as broad; 2nd and 3rd joint only slightly longer than broad; club with 2 joints, the 1st as long as the 3rd funicle joint, the 2nd narrower and terminated by a long spur.

Thorax with the pronotum transverse, finely shagreened; mesonotum about twice as broad as long, finely reticulated, the posterior part of the median lobe more or less striate; parapsidal furrows complete, terminating behind in small, oval grooves; scutellum entirely covered with fine longitudinal striae, which meet behind, forming a short reticulated area; propodeon smooth and shining, with the median carinae diverging strongly behind. Wings broadly rounded at tip, reaching beyond the end of the abdomen; marginal vein slightly longer than the submarginal; stigmal and postmarginal veins very short. Legs normal, narrow, the hind coxae smooth; tibial spurs a little shorter than the metatarsi.

Abdomen as long as the thorax, pointed behind; petiole a little broader than long, dull; 2nd segment occupying half the length of the abdomen, smooth and shining; the following segments short, transverse, less shining. Ovipositor scarcely protruding.

♂. Quite similar to the female; antennal scape scarcely thicker, the 3 funicle joints subequal in length. Abdomen shorter than the thorax, truncate posteriorly, with the petiole quadrate or a little longer than broad.

Length: ♂ 1·1–1·6 mm.; ♂ 1–1·3 mm.

TANGANYIKA: Arusha, Ngare ol Mytoni, 1 ♀ 2 ♂, vii.1929; Arusha, Vickers Estate, 19 ♀ 27 ♂, vii.1932; Moshi, Xeno Plant., 4 ♀ 6 ♂, 29.x.1934; Moshi, Kichoni Plant., 25 ♀ 7 ♂, xi–xii, 1934; Moshi, 38 ♀ 32 ♂ xi-xii, 1934 (o); Uru Distr., Kilimandjaro, 16 ♀ 10 ♂, xii.1934 (*A. H. Ritchie*). UGANDA: N. R. Estate, 1 ♀ 8 ♂, 15.vii.1924 (*H. Hargreaves*). KENYA COL.: Kiambu, 8 ♀ 4 ♂, 1932 (*R. H. LePelley*).

All are parasites of *Leucoptera* on coffee, except the series marked (o), which was bred from *Leucoptera* on *Oxyanthus speciosus*.

In the key of African species given by Waterston (1915) this species comes near *P. mediopunctata*, Waterst., from which it differs by the scutellum, which is not reticulate but striate on its largest part.

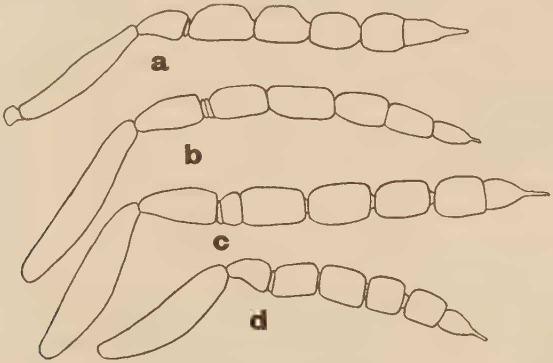

Fig. 3. Antenna, ♀ of: **a,** *Pleurotropis coffeicola*, sp. n.; **b,** *Achrysocharella ritchiei*, sp. n.; **c,** *Chrysocharis lepelleyi*, sp. n.; **d,** *Teleopterus violaceus*, sp. n. (All antennae in this and in the other figures are on the same scale).

Achrysocharella ritchiei, sp. n.

♀♂. Body bluish green, abdomen with the hind margins of the segments aeneous; antennae brownish black, the scape more or less yellow below; legs entirely yellow, except the coxae brownish green, and the hind femora brownish exteriorly. Male more golden green on the thorax, and with a rounded yellow spot at the base of the abdomen. Wings hyaline.

♀. Head very transverse, finely punctate, dull ; lateral ocelli as far distant from the eye margins as their own diameter ; eyes oval, diverging slightly towards the base ; cheeks short, more shining than the vertex. Antennae inserted near the clypeus, with 9 joints ; scape narrow and elongate, reaching to the level of the front ocellus ; pedicel narrow, about twice as long as broad ; two small, transverse annelli ; the 2 funicle joints about as long as and not much broader than the pedicel ; club with 3 joints, longer than the funicle, the last joint narrow and terminating in a spur.

Thorax with the mesonotum and scutellum closely punctate, dull ; propodeon and hind part of mesopleuri more shining. Mesonotum broader than long, with complete parapsidal furrows, which are more shallow at end ; scutellum as broad as long, with a broad and straight base against the mesonotum ; propodeon rather large, almost smooth, finely shagreened in the middle, without median carina. Wings reaching a little beyond the end of the abdomen, broadly rounded at tip, the greatest breadth more than half the entire length ; marginal vein more than twice as long as the submarginal vein ; stigmal vein almost sessile, with an oval knob ; post-marginal vein very short, almost wanting ; marginal ciliae short. Legs narrow, normal.

Abdomen shorter and narrower than the thorax, depressed, the sides parallel until the 5th segment, than pointed ; tergites dull, but more finely punctate than the thorax. Ovipositor not protruding.

♂. Smaller than the female ; antennae with the joints similar to those of the female, but narrower.

Length : ♀ 1·4–1·7 mm. ; ♂ 0·8–1·1 mm.

TANGANYIKA : Arusha, 6 ♀ 5 ♂, vii,1932 : Moshi, 28 ♀ 9 ♂, x–xi.1934 ; Uru Distr., Kilimandjaro, 2 ♀ 2 ♂, xii.1934 (*A. H. Ritchie*). NYASALAND : Ncheu, 3 ♀ 5 ♂, vii.1929 (*C. Smee*). KENYA COL. : Kiambu, 1 ♀ 2 ♂, 1932 (*R. H. LePelley*).

All are labelled " ex *Leucoptera coffeella* " or " ex coffee leaf-miner."

This species, with two annelli in the antennae, comes best in the genus *Achrysocharella*, Girault, but is also closely related to the genus *Achrysocharis*, Girault. It is the first species of that genus known from Africa, although another related species, with only one annellus in the antennae, *Achrysocharis formosa*, Westw., var. *erythraea*, Silv., has been found in Erythraea parasitising the olive fly, *Dacus oleae*. *A. ritchiei* differs from it by the hyaline wings, the almost entirely yellow legs and the more bluish-green coloration of the thorax.

Closterocerus africanus, Waterst.

Waterston, Bull. Ent. Res., **15,** 1925, p. 392.

Three specimens of *Closterocerus* have been found in Tanganyika, Arusha (1 ♂ 1 ♂, vii.1932) and Moshi (1 ♀, x.1934), all labelled "ex coffee leaf-miner." They agree exactly with Waterston's description and with the type in the British Museum ; the only difference being that the thorax is more shining green and violet, especially on the sides. Otherwise the coloration of body, antennae and legs is the same, as well as the form of the three transverse bands on the wing and the relative length and breadth of the antennal joints.

The biological difference seems greater, as *C. africanus*, Wat., has been bred in West Africa (Gold Coast), from the eggs of a Hispid beetle ; but it must be remembered that very little is known about the biology of *Closterocerus*, which is probably a hyperparasite. An American species, *C. cinctipennis*, Ashm., has been obtained in the U.S.A. both from the eggs of *Brachys* spp. (BUPRESTIDAE) and from Lepidopterous leaf-miners, *Phyllonorycter* spp.

Another species, *C. cofeellae*, Ihering, is a parasite of *Leucoptera* in Brazil, but not much is known about it, the description and figure being both incomplete.

Chrysocharis lepelleyi, sp. n.

♀♂. Bluish-green ; head more or less purple at base of face ; thorax slightly purple on the sides ; abdomen bluish green at base, aeneous behind ; antennae brown, scape more yellowish ; legs entirely light yellow, except the coxae which are black with greenish reflections.

♀, Head transverse, as broad as the thorax ; eyes large, covering the entire sides of the head, finely ciliate ; cheeks very short ; lateral ocelli a little more distant from each other than from the margin of the eyes. Antennae inserted above the clypeus, with 9 joints ; scape slightly broadened in the middle, about 4 times as long as broad ; pedicel twice as long as broad ; 2 annelli, the first very small, transverse, the second larger, as long as half its breadth ; funicle with 3 joints, the first two subequal in length, 1·5 times as long as broad, the third shorter, scarcely longer than broad ; club with 2 joints, the second terminating in a rather long spur.

Thorax with the mesonotum strongly reticulated, but shining ; parapsidal furrows entire and strongly marked ; scutellum with a slightly weaker reticulation ; propodeon smooth and shining. Wings large, reaching far beyond the end of the abdomen ; marginal vein clearly longer than the submarginal ; stigmal vein about as long as 1·5 of the marginal ; postmarginal vein twice as long as the stigmal ; discal ciliation not very close, but regular from the level of the base of the marginal vein, with a row of ciliae along the hind margin of the wing ; marginal ciliae short.

Abdomen about as long as the thorax, slightly narrower, with a short petiole, which is twice as broad as long ; the rest of the abdomen depressed, with the sides slightly diverging from the base, then converging strongly at tip. Ovipositor scarcely protruding.

♂. Similar to the female.

Length : ♀♂ 1—1·6 mm.

KENYA COL. : Kiambu, 1932, 10 ♀ " ex leaves mined by *Leucoptera coffeella* " (*Dr. R. H. LePelley*). TANGANYIKA : Moshi, Xeno Plant., x.1934, 3 ♀ 2 ♂ " ex coffee leaf-miner " (*A. H. Ritchie*).

This is the first species of *Chrysocharis* known from Africa.

Teleopterus violaceus, sp. n.

♀♂. Body green with violaceous reflections, sometimes more violaceous on the thorax or only on the sides of head and thorax ; abdomen violaceous at base and tip, more or less greenish above in the middle, with the end of the segments aeneous. Antennae black. Legs brownish black, with the trochanters, knees, end of tibiae, especially on the middle tibiae, and the tarsi yellow. Wings hyaline.

♀. Head transverse, as broad as the thorax ; eyes large, oval, with the inner margins parallel ; cheeks very short. Antennae inserted near the base of the face, with 8 joints ; scape reaching to the ocelli, slightly broadened, four times as long as broad ; pedicel short, triangular ; one small annellus ; 2 funicle joints, both short, a little longer than broad ; club with 3 joints, the first two subquadrate, the third narrower and terminating in a spur.

Thorax not longer than broad, finely and closely reticulated, dull, except the propodeon, which is smooth and shining. Pronotum large, triangular ; mesonotum transverse, with complete parapsidal furrows ; scutellum rounded, as long as the mesonotum ; propodeon short, with lateral grooves but without median carina. Wings large, broadly rounded at tip ; marginal vein longer than the submarginal and about four times as long as the stigmal vein ; postmarginal vein slightly shorter than the stigmal ; discal ciliae short, not very close, limited below by a row of ciliae extending from the end of the submarginal vein to the tip of the wing ; marginal ciliae short on the fore wing, longer on the hind wing. Legs narrow, normal.

Abdomen depressed, a little longer than and as broad as the thorax, smooth; petiole very short, transverse. Ovipositor scarcely protruding.

♂. Similar, but smaller; antennae narrower, the funicle and club joints a little longer than broad; abdomen shorter than the thorax, broadening somewhat towards the tip, where it is rounded.

Length: ♀ 0·9–1·1 mm.; ♂ 0·75 mm.

TANGANYIKA: Arusha, Burka Est., 1 ♀ 2 ♂, vii.1932; Moshi, Kichoni Plant., 1 ♀, xi.1934 (*A. H. Ritchie*). KENYA COLL.: Kiambu, 2 ♀, 1932 (*R. H. LePelley*). NYASALAND: Ncheu, 3 ♀, vii.1929 (*C. Smee*).

All series labelled " ex coffee-leaf miner " or " ex *Leucoptera coffeella*."

The genus *Teleopterus* was erected by Silvestri (1914) for a species, *T. notandus*, Silv., found in Erytraea as a parasite of *Dacus oleae*. It is closely related to the genus *Achrysocharis*, Girault, which has also only one annellus in the antennae. But it may be distinguished specially by the ciliation of the fore wings, where the discal ciliae are delimited by three rows of hairs, one all along the hind margin and two diverging from the stigmal vein. *T. violaceus* has the discal ciliae more numerous and more close than *T. notandus*; it differs further by the following characters: the body is more violaceous green, the thorax is finely but clearly reticulated and dull, only the propodeon being smooth, the antennal joints are broader, only slightly longer than broad, the last joint terminating in a longer spur.

Derostenus coffeae, sp. n.

♀♂. Shining bluish green, face more or less violaceous, the male also sometimes with the scutellum more or less purple; abdomen aenous black from the third segment. Antennae black, scape yellow. Legs light yellow, the end of the anterior femora slightly, a line below the middle femora and the hind femora above, black. Wings hyaline.

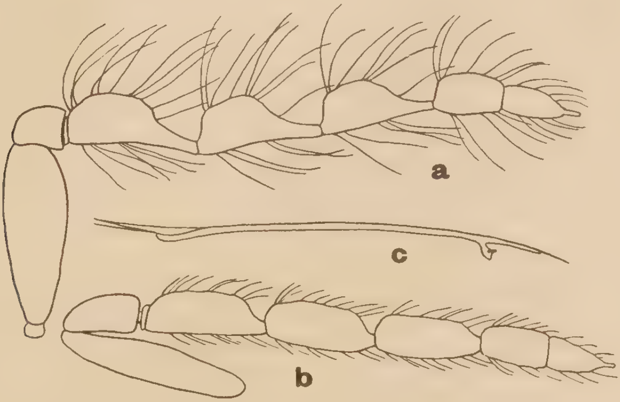

Fig. 4. *Derostenus coffeae*, sp. n.: **a**, antenna of ♂; **b**, antenna of ♀; **c**, wing nervature.

♀. Head twice as broad as long, vertex broad, the ocelli in a regular triangle; from in front the head is rounded, the eyes large, ciliate, the face impressed above the antennae, with a short longitudinal furrow below the front ocellus. Antennae inserted at the level of the base of the eyes; scape narrow, short, not reaching to the front ocellus; pedicel about twice as long as broad; annellus very small, transverse; funicle with 3 joints, all longer than the pedicel, about three times as long as broad, broadened in the middle, narrowed at tip, covered with hairs shorter than the breadth of the joint ; club with 2 joints, slightly longer than the preceding joint.

Thorax with the mesonotum finely rugulose, or more or less transversely striate, with a slight depression along the middle ; parapsidal furrows complete, deep, broadening towards the scutellum. Mesopleurae smooth. Scutellum very finely shagreened, with a slight median depression at base. Propodeon rather large, smooth, with four longitudinal carinae, the two median diverging slightly behind. Wings with a long marginal vein, about twice as long as the submarginal ; stigmal vein very short, subsessile ; postmarginal vein three times as long as the stigmal ; marginal ciliae very short ; discal ciliation relatively long and not very close.

Abdomen oval, elongate, pointed behind, longer than the thorax ; petiole short, a little broader than long ; the other segments subequal in length, smooth, the terminal ones finely shagreened, dull. Ovipositor scarcely protruding.

♂. Similar to the female, from which it differs only by the form of antennae and abdomen. Antennae with the scape short ; pedicel scarcely longer than broad ; annellus very small ; the 3 funicle joints broadened on the lower 2/3, then narrowed in the form of a petiole at tip ; first segment the longest, three times as long as the pedicel, the following segments gradually shorter ; club with 2 joints, a little longer than the first funicle joint ; funicle and club joints covered with long hairs, which are as long as or longer than the joints. Abdomen with the petiole as long as the propodeon, the rest of the abdomen oval, a little shorter and narrower than the thorax, the second segment the longest.

Length : ♀ 2·1–2·3 mm. ; ♂ 1·4–1·6 mm.

TANGANYIKA : Bukoba, 19.vii.1935. 18 ♀ 9 ♂ "ex coffee leaf-miner" (*A. H. Ritchie*).

The genus *Derostenus*, Westw., is still inadequately known. The *Derostenus* spp., from America, described by Crawford, belong, I believe, better among the OMPHALINI near *Closterocerus* and *Achrysocharis*. According to Thomson, Ashmead and Schmiedeknecht, *Derostenus* is an Entedonine, with the abdomen clearly petiolate, the propodeon well developed and the stigmal vein short and sessile. This genus has, moreover, antennae with 8 joints, with one annellus, a 3-jointed funicle and a 2-jointed club, a postmarginal vein longer than the stigmal and mostly yellow legs and antennal scape. The genotype is *D. gemmeus*, Westw. ; we have been able to see some males of that species in the British Museum, which by their general form resemble *D. coffeae*. The latter species differs, however, in the male by the form of the funicle joints and in the female by the elongate abdomen with a shorter petiole, and may eventually be referred to a new genus.

Subfam. TETRASTICHINAE.

Tetrastichodes leucopterae, sp. n.

♀. Body black with greenish reflections on head and thorax ; abdomen with the first three segments yellow above and below, bordered by greenish-black lines on the sides, the rest of the abdomen black. Antennae light brown, scape and pedicel yellow. Legs entirely light yellow.

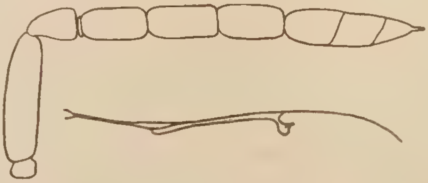

Fig. 5. *Tetrastichodes leucopterae*, sp. n., ♀ : antenna and wing nervature.

Head narrow, seen from in front rounded, the eyes short oval, the cheeks converging towards the mouth ; lateral ocelli as far distant from the eye-margins as their own diameter. Antennae with 9 joints ; scape stout and short, reaching just to the front ocellus ; pedicel not much longer than broad ; only one small annellus ; the 3 funicle joints elongate, longer than the pedicel, subequal in length, about twice as long as broad ; club with 3 joints, as long as the two preceding joints together, the third small, triangular, terminated by a spur.

Thorax with the pronotum triangular, not elongate ; mesonotum finely reticulated, dull, with complete parapsidal furrows, but without median furrow ; scutellum more finely shagreened, with the four longitudinal furrows, two median and two lateral, well marked ; propodeon granulose, dull, with a median carina. Wings large and broad ; marginal vein slightly longer than the submarginal ; stigmal vein short, almost sessile ; postmarginal almost wanting ; marginal and discal ciliae short. Legs narrow.

Abdomen more or less rounded, as long and as broad as the thorax, the first segment as a short rounded petiole, the following segments subequal in length, the terminal ones slightly shorter. Ovipositor not protruding.

♂. Unknown.

Length : 0·7–1·1 mm.

Tanganyika : Moshi, xi.1934, 5 ♀ " ex *Leucoptera* from *Cremaspora africana* " ; Moshi, xi–xii.1934, 3 ♀ " ex *Leucoptera* on *Oxyanthus speciosus* " ; Uru, Distr., Kilimandjaro, xii.1934, 1 ♀ " ex *Leucoptera* on *Coffea arabica* " (*A. H. Ritchie*).

This species is characterized among the Tetrastichini by the shortly petiolated abdomen and the shortness of the stigmal vein. It has nevertheless all the characters of the *Tetrastichodes* by the absence of the median furrow on the mesonotum and the distinctly four-grooved scutellum. A very short petiole may be seen in several species of *Tetrastichus* and *Tetrastichodes*, especially those with more or less rounded abdomen ; it may even be considered to be always present, but it is so small in most species as to be invisible except in microscopical preparations. The genus *Ceratoneura*, Ashm., has a stronger and more conspicuous petiole, and has no inner furrows on the scutellum.

In order to render the determination of these small parasitic Hymenoptera easier to those working on coffee pests in Africa, we have prepared a key including all the known African parasites of *Leucoptera*. This key must nevertheless be used only in connection with the complete descriptions.

1.—Wing nervature forming distinct closed cells at the base of the forewings (Braconids) 2

Wings without closed cells, except a narrow costal cell above the submarginal vein (Chalcids) 3

2.—Head orange-yellow, abdomen white at base ; antennae with 14 joints ; first abscissa of radial vein very short, not longer than broad, the transverse cubital vein long and straight ; legs entirely yellow .... *Mirax leucopterae*, Wilk.

Head, thorax and abdomen entirely black ; antennae with 18 joints ; first abscissa of radial vein in a curved line with the transverse cubital, their point of junction indeterminable ; legs reddish yellow, tip of hind tibae and hind tarsi brown .... *Apanteles bordagei*, Giard

3.—Hind coxae broad, flattened and rounded, covering partly the sides of the abdomen ; hind legs elongate, wings narrow...... *Elasmus leucopterae*, Ferr.

Hind coxae small, oval ; legs and wings normal 4

4.—Body mostly yellow, with black stripes on thorax or abdomen, or both ...5

Body dark, at most a yellow spot at base of abdomen..............................7

5.—Black, narrow stripes or lines on thorax and abdomen ; antennae short and broad..*Atoposoma variegatum*, v. *afra*, Silv.

Dark stripes different ; antennae narrower..6

6.—Body yellow, only two transverse black stripes on abdomen ....
Cirrospilus cinctiventris, sp. n.

Thorax yellow with a broad longitudinal stripe along the back ; abdomen brown with yellow sides....................*Cirrospilus longifasciatus*, sp. n.

7.—Antennae with 13 joints ; scape, pedicel, 2 small annelli, 6-jointed funicle and 3-jointed club ; abdomen distinctly petiolate..........................
Trigonogastra nigricola, sp. n.

Antennae with less joints ; abdomen not or only shortly petiolate..............8

8.—Abdomen with a yellow spot at base 9

Abdomen entirely dark metallic..11

9.—Thorax black, with very short parapsidal furrows ; postmarginal vein longer than the stigmal vein ....*Eulophus borboricus*, Giard

Thorax dark green or golden, with distinct and complete parapsidal furrows ; postmarginal vein not developed or very short...............................10

10.—Thorax greenish black ; scutellum with distinct longitudinal furrows ; yellow spot covering the 3 basal segments of the abdomen ....
Tetrastichodes leucopterae, sp. n.

Thorax golden green ; scutellum without longitudinal furrows ; yellow spot very small, rounded near base of abdomen......................................
Achrysocharella ritchiei, sp. n. ♂

11.—Legs yellow, hind femora sometimes with black lines or more or less brown in middle 12

Legs mostly dark..14

12.—Abdomen of ♀ very elongate, pointed behind ; middle and hind femora with narrow black lines ; males with antennal joints rounded in the middle, narrowed at each end and covered with long hairs..........................
Derostenus coffeae, sp. n.

Abdomen of ♀ short oval, not longer than the thorax ; male antennae normal 13

13.—Thorax bluish green, reticulate, shining ; abdomen mostly aeneous ; legs entirely clear yellow, except coxae ; postmarginal vein longer than the stigmal vein.......................................*Chrysocharis lepelleyi*, sp. n.

Thorax bluish green, closely punctate, dull ; abdomen with transverse aeneous stripes at end of each segment ; legs yellow, hind femora brown outside ; postmarginal vein much shorter than the stigmal vein..........................
Achrysocharella ritchiei, sp. n.

14.—Wings with three curved transverse stripes ; antennae broadened and flattened..*Closterocerus africanus*, Wat.

Wings hyaline ; antennae normal...15

15.—Mesonotum with only very short parapsidal furrows ; antennae with 9 joints ; scape, pedicel, one small annellus, 4-jointed funicle and 2-jointed club ; wings long and not very broad at tip ; submarginal vein not broken..*Sympiesis bukobensis*, sp. n.

Mesonotum with complete parapsidal furrows; antennae with 8 joints; scape, pedicel, one annellus, 3-jointed funicle and 2-jointed club; wings broadly rounded at tip; submarginal vein broken..........................16

16.—Antennae and legs dark green, only tarsi whitish; thorax shining dark green; scutellum striate; propodeon with two diverging carinae .... *Pleurotropis coffeicola*, sp. n.

Antennae and legs brown, knees, tip of tibiae and tarsi yellow; thorax violaceous-green, mesonotum and scutellum closely reticulate, dull; propodeon with only one median carina...........*Teleopterus violaceus*, sp. n.

References.

Bordage, E. (1913). Les ennemis de l'Elachiste (*Cemiostoma cofeella*) et de la Gracilaire (*Gracilaria cofeifoliella*) du caféier. Notes biologiques recueillies à l'île de la Réunion V.—Bull. Sci. Fr. Belg., **47,** pp. 384–385.

Box, H. E. (1923). The bionomics of the white coffee leaf-miner, *Leucoptera cofeella,* Guér., in Kenya Colony.—Bull. Ent. Res., **14,** pp. 133–145.

——. (1927). Notas sobre dos insectos perjudiciales a las matas de café en Venezuela.—Caracas, Camara de Comercio, 19 pp.

Bruner, S. C. (1929). Reseña de las plagas del cafeto en Cuba.—Circ. Estac. Exp. Agric., no. 68, 38 pp.

Ferrière, C. (1931). Notes on African Chalcidoidea.—Bull. Ent. Res., **22,** pp. 127–135.

Giard, A. (1898). Sur l'existence du *Cemiostoma cofeella* Guér. à l'île de la Réunion. —Bull. Soc. Ent. Fr., pp. 201–203.

——. (1903). Sur un moyen de lutte contre les insectes nuisibles à habitat très étendu.—Bull. Sect. Agric. Col., **1,** 1901–02, Notes et mém., p. 22.

Hooker, C. W. (1912). Ann. Rep. Porto-Rico Agric. Exp. Sta., 1912, pp. 34–38.

v. Ihering, R. (1914). Tres Chalcididas parasitas do " Bicho do Café," *Leucoptera cofeella.*—Rev. Mus. Paul., **9,** pp. 85–104, 364.

Mann, B. P. (1872). The white coffee-leaf miner.—Amer. Nat., **6,** pp. 332–340 & 596–607.

Ritchie, A. H. (1935). Report of the Entomologist, 1934.—Rep. Dep. Agric., Tanganyika, 1934, pp. 73–83.

Silvestri, F. (1914). Viaggio in Eritrea per cercare parassiti della mosca delle olive.—Boll. Lab. Zool. Portici, **9,** pp. 186–226.

Waterston, J. (1915). Notes on African Chalcidoidea. II.—Bull. Ent. Res., **5,** pp. 343–372.

——. (1925). On some Eulophid parasites of the oil palm Hispid beetle.—Bull. Ent. Res., **15,** pp. 385–395.

Wilkinson, D. S. (1934). On some *Apanteles.*—Stylops, **3,** pp. 145–156.

Wolcott, G. N. (1931). El minador de las hojas del café.—Circ. Porto Rico Ins. Exp. Sta., **52,** 12 pp.

v. Zwaluwenburg, R. H. (1914). Ann. Rep. Porto Rico Agric. Exp. Sta., p. 31.

——. (1917). Insects affecting coffee in Porto Rico.—J. Econ. Ent., **10,** pp. 513–517.

A NEW SPECIES OF HABROLEPIS PARASITIC IN *CHRYSOMPHALUS AURANTII*, MASK.*

By Harold Compere,

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The California red scale, *Chrysomphalus aurantii*, Mask., is probably the most important Coccid pest of citrus, although other species, notably *Lepidosaphes beckii*, Newm. and *Chrysomphalus aonidum*, Linn., are injurious to citrus over a greater geographical range. In many countries where the latter species injuriously infest citrus, the fruit is not produced for export, local marketing standards do not prevent the sale of scale-infested fruits, and untreated orchards are seldom seriously and permanently injured.

On the other hand there is no other citrus-infesting Coccid which more quickly and permanently injures a tree than *Chrysomphalus aurantii*. In areas where it has developed a resistance to hydrocyanic acid gas it is the most difficult of all Coccids to kill. A large part of the world's most valuable commercial citrus orchards are in the semi-arid regions of California, South Africa and Australia, where *C. aurantii* is most injurious. Here much of the fruit is produced for export, standardization laws permit the marketing of only clean fruits, and the treatment of groves infested with *C. aurantii* is generally necessary.

Since 1900, many entomologists have believed that China is the native home of *Chrysomphalus aurantii*. The species known as *C. aurantii* in China, India and Japan, which is parasitized by *Comperiella bifasciata*, How., *Casca chinensis*, How., *Prospaltella aurantii*, How., and *Aspidiotiphagus citrinus*, Craw., is not the same as the species named *C. aurantii* in California. The most competent taxonomists have not detected any differences betwen Asiatic and California samples of so-called *C. aurantii*, nor have entomologists who have studied the two forms under natural conditions noticed any difference in their habits or appearance. But that the two forms are different is shown by the failure of the Oriental parasites to develop in California red scale, *C. aurantii*, while they freely develop in the Asiatic form. These Chalcidoids readily oviposit in California *C. aurantii*, but their eggs or larvae are destroyed by this Coccid's immune reaction.

There are reasons for suspecting that eventually the so-called Oriental red scale may prove to be the same as the yellow scale, *Chrysomphalus citrinus*, Coq. In the practical work of biological control it is most important to recognise these different races, varieties, species, or whatever they may be called, since they are the units with which we are dealing. Because of the uncertainty regarding the identity of *C. aurantii* it is impossible at this time to prepare a comprehensive account regarding this pest.

The red scale, *Chrysomphalus aurantii*, Mask., came to the attention of entomologists in three widely separated parts of the world almost simultaneously. It was first described by Maskell in 1878 from specimens taken from citrus fruits imported into New Zealand from Sydney, Australia. It is reported to have been known to the orchardists in New South Wales for many years prior to 1878. The existence of *C. aurantii* came to the attention of European entomologists in 1879, when Gennadius was called to the island of Chios to study a " disease " which was injurious to the

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orange groves there. In 1878, *C. aurantii* was first introduced into California on six lemon trees imported from Australia, and within ten years it was rated as one of the most injurious pests in the State. On the island of Cyprus, where it is rated most injurious, *C. aurantii* attracted attention as early as 1890. In 1897, C. P. Lounsbury reported *C. aurantii* as the most injurious pest of citrus in Cape Colony, and was of the opinion that it was well established there at least fifty years before his arrival in 1895.

The observations of the writer in regard to *Chrysomphalus aurantii* in Japan, China, India and South America cannot be reported upon fully because of the uncertainty of many determinations. In general, however, *C. aurantii* is widely distributed and often abundant in tropical regions of summer rainfall and high humidity. Under such conditions it occurs as a pest of rose bushes rather than of citrus. The form which is found almost everywhere in India and China on such plants as citrus, Cycas and Euonymus, often heavily parasitized by the Chalcidoids previously mentioned, is different from the species known as *C. aurantii* in California. The species which occurs in India, Brazil and Paraguay, often abundant and injurious on rose bushes and immune to parasitism, is supposedly the same as the California *C. aurantii*. In Brazil, Paraguay and India rose bushes heavily infested with *C. aurantii* were often found in contact with citrus; which was free of this scale. The species which infests indigenous *Podocarpus* spp. in Japan and *Podocarpus andina* in Buenos Aires, Argentina, is not the *C. aurantii* of California. The determination of the Coccid injurious to citrus in Misiones, north-east Argentina, as California *C. aurantii* is questionable. In the semi-arid regions of Africa, Australia, Central Chile and European countries in the eastern Mediterranean Basin, where climatic conditions are similar to those of the California citrus area, the red scale which commonly infests citrus is supposed to be the same as that known as *C. aurantii* in California.

In 1894, under the title " The Hymenopterous Parasites of the California Red Scale," Dr. L. O. Howard published a paper in which he mentioned six species of Chalcidoids as parasites of the California red scale. However, Dr. Howard did not follow the lead of Comstock and Riley in denying the existence of yellow scale or "*Aspidiotus aurantii*" var. "*citrinus*." As a matter of fact none of the species mentioned by Howard in his article are now known as parasites of *Chrysomphalus aurantii*.

Aphytis chrysomphali, Mercet, an Aphelinid which occurs in Asia, Europe, Africa, Australia, North America and South America, is frequently reared from *Chrysomphalus aurantii* and other Diaspidine Coccids. This is not an internal parasite, since the larvae feed upon the scales ectoparasitically. *Aspidiotiphagus lounsburyi*, Berlese & Paoli, which develops in the *C. aurantii* that infests roses in Brazil and Africa, is the only previously described species now recognised as an internal parasite of California red scale. This parasite seems to develop rarely in *C. aurantii*, although it may be abundant in the same area on other hosts.

The search for useful insects that might be of aid in controlling the red scale, *Chrysomphalus aurantii*, in California is a project of the University of California Citrus Experiment Station. The various regions of the world considered most likely to yield parasites of value have been explored with negative results.

In June, 1935, Mr. W. K. Roux, chief entomologist, Letaba Estate, Zebediela, Transvaal, Union of South Africa, sent a small lot of reared parasitic insects to the Citrus Experiment Station for identification. Among them were specimens of the *Habrolepis* described in this article. According to Roux's letter they were reared from *Chrysomphalus aurantii*, Mask., collected at the Letaba Estate, Transvaal. In reply to an inquiry regarding the possibility that *Habrolepis* might possibly have issued from another host, Mr. Roux sent two samples of *Habrolepis* which are *in situ*. Although the hosts and the *Habrolepis* within are unstained, the pygidial characters are clearly visible. These scales containing *Habrolepis* appear taxonomically indistinguishable from California red scale, *C. aurantii*, California yellow scale, *C. citrinus*, or the so-called Asiatic red scale, *Chrysomphalus* sp. If the red scale which infests citrus in Transvaal is the same as the California red scale, there is a possibility that this new parasite may be of some value in California, and efforts to secure a colony are being made.

In the collection of the Citrus Experiment Station are more species of undescribed *Habrolepis* from Africa than have been described from all other parts of the world. The richness in species of the African fauna seems to indicate that the genus *Habrolepis* originated there ; on the other hand, the species of *Chrysomphalus* with which we are concerned are commonly supposed to be of Oriental origin. On the basis of this evidence, *Habrolepis rouxi*, sp. n., is suspected to be native to Africa, its original host being some indigenous Coccid and its parasitism of the red scale only a recent development.

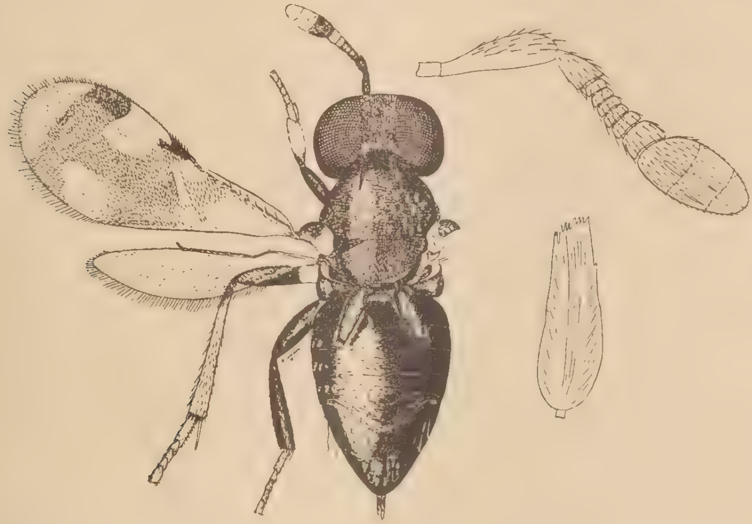

Fig. 1. *Habrolepis rouxi*, Comp., sp. n.

Habrolepis rouxi, sp. n.

This belongs to the group of *Habrolepis* species which are distinguished by two abnormally enlarged, flattened setae at the apex of the scutellum and two smaller, narrower, flattened setae on the vertex. *Habrolepis dalmani*, Westwood, and *H. pascuorum*, Mercet, can be readily separated from the new species by the completely blackish middle femora. In *Habrolepis oppugnati*, Silvestri, the club is shorter than the funicle, the ovipositor not so strongly exserted as in this species, and the apex of the forewings more extensively infuscated.

Female.—Frontovertex, mesocutum, and disk of scutellum punctate reticulate, bright, metallic bluish green. Sides of scutellum highly polished, violaceous. Abdomen mostly shining, dark metallic with violaceous reflections. Face greenish black. Scape, pedicel, more or less of the first four funicle joints, and the basal club joint black to dark brown ; the remainder of antennae testaceous. Middle legs with basal one-third of the femora colourless. All the tarsi (except distal joints), middle tibiae, except the basal ends, and most of front tibiae pallid, brownish yellow, or colourless. Forewings with integumentary infuscation and coarse, blunt cilia arranged in a pattern as shown in the figure.

Ocelli in an acute triangle, the posterior pair less than one-half their own diameter from the orbits and three or four times their own diameter from the occipital margin. Tibial spur of middle legs as long as the basitarsus. Antennal club almost as long as the pedicel and funicle joints combined. First five funicle joints of almost uniform length and all very slightly progressively increasing in width ; the sixth funicle joint about twice the size of the first. Other details of antennae as shown in the figure.

Length : 0·9 mm.

Described from 12 females, holotype and paratypes, reared from *Chrysomphalus aurantii* Mask., by R. K. Roux, Letaba Estate, Zebediela, Transvaal, Union of South Africa, 11th July, 1935. Holotype to be deposited in the British Museum and paratypes in the United States National Museum.

NEW INJURIOUS CURCULIONIDAE (COL.) FROM SOUTH AMERICA.

By Sir Guy Marshall.

Subfamily Leptopinae.

Premnotrypes fractirostris, sp. n.

♂♀. Derm shiny testaceous brown (perhaps immature), with rather sparse minute grey scales, mostly with a coppery reflection and not concealing the integument.

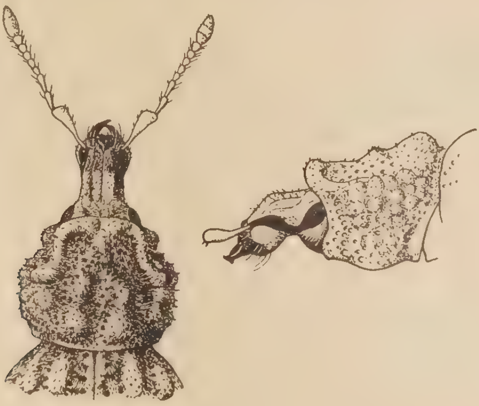

Fig. 1. *Premnotrypes fractirostris*, Mshl., sp. n., ♀ ; dorsal and lateral views of head and prothorax.

Head with rather dense suberect scaling and a very deep elongate frontal fovea. *Rostrum* about as long as the funicle, gradually narrowing from the base to the middle, then rapidly widening anteriorly, being slightly wider across the genae in ♂ than in ♀, abruptly bent downwards at two-fifths from the base, with a median stria that is almost concealed by the dense erect narrow scales and a broader parallel furrow on each side of it ; the triangular epistome elevated, shiny, bare and almost impunctate. *Antennae* with the scape only just reaching the front margin of the eye, very broadly clavate in the distal two-thirds ; the funicle with joints 1 and 2 subequal, 7 slightly transverse, or as long as broad. *Prothorax* slightly transverse, strongly rounded at the sides, widest at the middle, broadly constricted laterally at the apex, the apical margin strongly produced and broadly rounded, the base gently arcuate and immarginate ; the dorsal part of the apical margin broadly and obtusely elevated, the ridge divided in the middle by a short, shallow, longitudinal sulcus and continued backwards on each side (at a much lower level) to join an irregular group of small obtuse tubercles, which are divided in the middle by a deep narrow transverse furrow ; the median area of the dorsum strongly and deeply punctate, with two large conical tubercles in the middle of the base and two smaller ones in the middle of the disk ; all the elevated areas set with short stout suberect setae. *Elytra* broadly ovate, the rows of large deep punctures somewhat irregular ; interval 3 with a short broad costa and behind it a row of about seven variable obtuse tubercles ; interval 5 with an obtuse sub-basal tubercle and four or five behind it ; interval 7 with eight or nine unequal tubercles ; the other dorsal intervals with scattered transverse ridges, especially in ♂; the raised areas with greyer scaling and short, stout, suberect black setae. *Legs* with rather sparse narrow scales and erect setae.

Length 5·5–6·0 mm., breadth 2·7–3·0 mm.

Peru: 2 ♂♂, 1 ♀.

Bred in England from potatoes received from Peru.

Premnotrypes solani, Pierce 1914, which also attacks potatoes in Peru, differs *inter alia* in having the rostrum almost straight, with the epistome semi-elliptical; the prothorax is angulate laterally and widest behind the middle, and the base has a transverse row of six tubercles.

Plastoleptops, Heller 1935, is clearly synonymous with *Premnotrypes*, Pierce, and *P. solanivorax*, Hllr., differs from the present species in its gently curved rostrum and in the presence of a transverse row of four sharp tubercles on the apical margin of the pronotum.

Hypsonotus parceguttatus, sp. n.

♀. Derm black, with blackish scales and a few coppery spots; prothorax with a few coppery scales in the basal angles; elytra with the following coppery markings: an indefinite macular stripe on the lateral margin, an irregular macular band across the declivity and sometimes another near the apex, a few scattered minute spots, mostly in the striae, and a spot at the base of interval 3 or on 3 and 4; the underside with sparse small scales, which are mostly pale greenish on the sternum and coppery at the sides of the venter.

Head with the line of the forehead almost continuous with that of the rostrum, finely aciculate and scarcely punctate dorsally; the forehead with a distinct supra-ocular ridge, flat, with rather strong shallow punctures and a deep elongate median fovea. *Rostrum* rather slender, as long as the pronotum, strongly dilated at the apex, with three parallel dorsal carinae, the outer ones being continuous with the supra-ocular ridges. *Antennae* with the two basal joints of the funicle equal. *Prothorax* nearly as long as broad (9 : 10), rounded laterally, widest well beyond the middle, shallowly constricted at the apex, feebly bisinuate at the base, the dorsal apical margin arcuate; dorsum almost flat longitudinally in the middle, the fine shallow punctures entirely hidden by scaling, only the small shiny separated granules showing through, without any median stria or carina; the pleurae more rugosely punctate, with less conspicuous flattened granules. *Scutellum* shield-shaped, with fuscous scaling. *Elytra* ovate, with prominent subrectangular shoulders, not sinuate laterally, but parallel-sided to the middle, with a subapical lateral constriction and obtuse posterior calli, the apices jointly subacuminate; the dorsal outline gently convex to the declivity, which is almost perpendicular, the suture only slightly raised behind; the striae rather shallow, the punctures, which contain no scale, very large in the basal half and abruptly becoming much smaller behind; the intervals about as broad as the punctures in the basal half, but not transversely costulate, much broader behind; the scales small and rounded, the dark setae very inconspicuous, short, recumbent. *Legs* with dark scaling and a patch or ring of coppery scales near the apex of the femora; the front tibiae incurved at the apex and indistinctly denticulate.

Length 8·0–11·0 mm., breadth 3·2–4·6 mm.

Brazil: Bahia, 2 ♀♀, adults feeding on leaves of cacao, 1935 (*Dr. G. Bondar*).

The nearest ally of this species is *H. aurarius*, Jek. 1859, which, however, has a very different appearance owing to its light brown scaling and coppery pink markings; the pronotum has two pink stripes and the elytra numerous large round pink spots; the punctures on the elytra are smaller, intervals 2 and 3 at the top of the declivity are much broader than 4 and 5 (of equal width in *parceguttatus*), and the pale setae are conspicuous.

Hypsonotus modestus, sp. n.

♂♀. Derm piceous uniformly covered above and below with fawn-coloured scales more or less mingled with paler ones, which do not entirely conceal the integument, and without any definite stripes or patches on either surface.

Head separated from the rostrum by a very shallow transverse impression, with fine close punctation ; the forehead transversely convex, without any trace of a supra-ocular ridge, and with a small median fovea. *Rostrum* comparatively short and stout, shorter than the pronotum, strongly dilated apically, with a sharp median carina and obtuse lateral ridges which diverge posteriorly and are sometimes indistinct. *Antennae* with joint 2 of the funicle somewhat longer than 1. *Prothorax* slightly transverse (6 : 7) in ♂, more so in ♀ (6 : 8), gently rounded laterally, widest beyond the middle, constricted at the apex, but not at the base, which is arcuate, the dorsal apical margin subtruncate ; dorsum flat longitudinally in the middle, with shallow dense rugulose punctation, the intervals becoming subgranulate laterally, and with an abbreviated narrow low median carina which is rarely obsolete ; the dorsal scales sparser and narrower than those on the elytra. *Scutellum* shield-shaped, with dense pale scaling, appearing paler than the elytra. *Elytra* broadly ovate in ♀, narrower in ♂, with broad subrectangular shoulders, behind which the sides are shallowly sinuate, laterally constricted near the apex, which is subacuminate ; the dorsal outline slightly convex to beyond the middle and rather steeply declivous behind, the suture somewhat elevated posteriorly ; the striae rather deep, with small separated punctures, each containing a scale and scarcely diminishing behind ; the intervals much broader than the striae, slightly convex and never transversely wrinkled ; the scales small and almost round, the setae inconspicuous, short, spatulate and closely recumbent. *Legs* with uniform pale fawn scaling ; the front tibiae distinctly incurved at the apex and strongly denticulate, the hind pair without any long apical tuft of setae in ♂. *Venter* of ♂ with the anal ventrite not emarginate at the apex nor costate in the middle, but with a shallow longitudinal lateral impression.

Length 8·5–16·5 mm., breadth 3·2–7·0 mm.

BRAZIL : Bahia, 3 ♂♂, attacking leaves of cacao, 1935 (*Dr. G. Bondar*), 6 ♀♀ (*Reed*).

Allied to *H. cervinus* and *obsoletus*, Jek. 1859. The former differs in having a longer and more slender rostrum, which is longer than the pronotum and has the lateral costae parallel ; the pronotum is much more finely punctate, not subgranulose, and has a shallow median stria in the basal half ; the elytra have large subquadrate punctures in the basal half and the intervals transversely costulate, and the scales are whitish and very narrow ; the two basal joints of the funicle are equal.

H. obsoletus also has a much more slender rostrum which is only slightly dilated at the apex and has parallel carinae ; the head has supra-ocular ridges ; the pronotum is convex longitudinally, bisinuate at the base, and with no trace of a carina ; the elytra are not constricted apically, and have large quadrate punctures and transverse costulae on the basal half, erect setae on the apical half, and a submarginal stripe of dense whitish scales.

Subfamily HYLOBIINAE.

Acallestes camelus, sp. n.

♂♀. Dull black, clothed above with minute earth-brown scales which are not contiguous ; underside bare, except for similar minute scales at the sides of the sternum and of the second ventrite.

Head entirely bare, opaque, with a few very minute shallow punctures, the forehead with a deep round fovea. *Rostrum* of ♂ as long as the pronotum, rather stout, gently curved, one-fourth wider beyond the antennae than in the parallel-sided basal half, entirely bare, smooth, without any trace of sulci or carinae, and with minute separated punctures throughout ; rostrum of ♀ about 0·5 mm. longer and with the antennae a little further from the apex, otherwise quite similar. *Antennae* rather stout, joint 2 of the funicle about as long as 1 and clavate, the remainder moniliform, becoming transverse distally. *Prothorax* transverse (4 : 5), strongly rounded laterally, widest at the middle, not constricted at the apex, subtruncate and finely marginate at the base, the dorsal apical margin gently arcuate (rarely truncate), the whole prothorax sloping upwards from the longitudinal axis of the elytra ; the dorsum longitudinally convex, highest at the middle, unevenly set with round or oval distant shiny granules, leaving a broad smooth median space. *Elytra* subpyriform, only slightly wider at the base than the prothorax, without any humeral calli, strongly dilated to behind the middle, then rapidly narrowed to the apices, which are jointly and obtusely rounded, without any subapical constriction or calli, and with a broad transverse depression across the base ; the dorsal outline rising rapidly from the base to behind the middle, then abruptly and steeply declivous (almost forming a right angle) straight to the apex ; the rows of small shallow punctures somewhat irregular in parts ; the intervals with rows of distant shining granules, only those on 1, 5 and 7 being fairly complete ; 2 with at most one granule on the basal half and a granulate tubercle at the top of the declivity ; 3 with a granulate tubercle at one-fourth from the base and another just before the declivity ; 4 often without any granules or with only one, two or three scattered ones ; 6 usually without any granules from the base to the top of the declivity where there is a small granulate tubercle and one or two granules behind it, but sometimes with one or two granules about the middle ; 8 with only a few granules near the apex, and 9 with a few near both base and apex ; all the granules bearing a short suberect seta. *Legs* rather slender and somewhat shiny, with sparse short recumbent setae ; femora blackish, red-brown at the base, all with a sharp tooth ; tibiae and tarsi red-brown, the former bisinuate on the lower edge and sinuate dorsally on the apical half. *Venter* much inflated basally in both sexes, the middle of the two basal ventrites with fine transverse granulation.

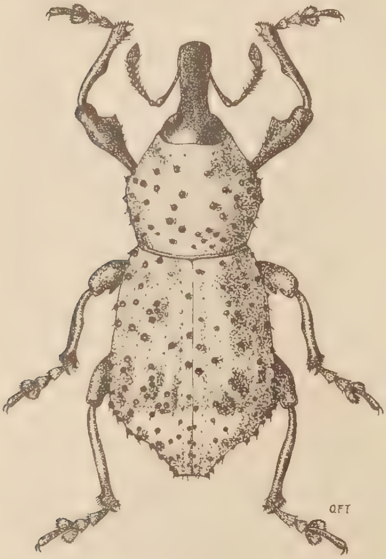

Fig. 2. *Acallestes camelus*, Mshl., sp. n., ♂.

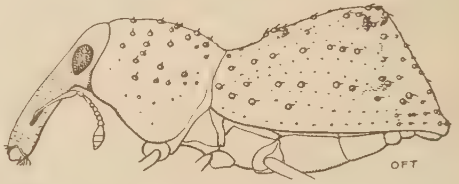

Fig. 3. *Acallestes camelus*, Mshl., sp. n., lateral view.

Length 10·5–12·5 mm., breadth 5·2–6·0 mm.

Brazil: Bahia, 5 ♂♂, 1 ♀, attacking leaves and fruit of cacao, 1935 (*G. Bondar*), 2 ♂♂ (*Williams*).

Two wingless species of *Heilipus*, *nodifer* and *retusus*, Boh., should be transferred to Pascoe's genus *Acallestes*, both being allied to the present new species. They differ, however, in lacking the inflation and granulation of the venter; further, the rostrum is longer and much more slender, the granules on the prothorax are much denser, the suture is raised on the declivity of the elytra, etc.

THE CONTROL AND ERADICATION OF PRICKLY-PEAR IN AUSTRALIA.

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(Plates XV–XVII.)

Introduction.

The present article discusses briefly the efforts to control the prickly-pear pest in Australia and indicates the signal success achieved by the investigation. The various phases of the activities of the Commonwealth Prickly-Pear Board are merely touched upon in this review. A comprehensive account of the investigations is in course of preparation and will, it is hoped, be presented in book form within two years.

The biological campaign against prickly-pear is an outstanding example of the control of a vigorous weed pest. At the present juncture it can be claimed that the great problem of *Opuntia inermis* and *O. stricta* has been solved. The enormous annual increase of these plants has been arrested. But of greater significance, the vast areas have been broken up and the major proportion of the pear has been destroyed. To-day, less than 10 per cent. of the former great body of the pest in Queensland and the northern areas of New South Wales survives. These statements are not intended to convey a mental picture of complete eradication over extensive tracts of country, but rather of extreme reduction of the former heavy infestation to light or scattered growth. In two prickly-pear districts in New South Wales the destruction has not reached the same stage of advancement, but very effective work has been accomplished, and finality is merely a question of time.

Approximately 25,000,000 acres of good grazing and agricultural land, previously a wilderness of dense prickly-pear, have been retrieved to such an extent that they are rapidly being developed and brought into production.

The remarkable results are due to the activities of one insect, the Argentine moth-borer, *Cactoblastis cactorum*, Berg.

The Problem for Solution.

In order that the results of the biological control of prickly-pear in Australia may be appreciated, the nature of the problem must be understood. Briefly, the problem was the control and eradication of an introduced weed pest that has overrun and rendered valueless very great areas of country, that was spreading at an alarming rate, and that, because of the cost of treatment, could not be combated by cultural, mechanical and chemical methods.

The prickly-pears of the genus *Opuntia*, family Cactaceae, are indigenous to North and South America. Many species have, for various reasons, been introduced into other parts of the world. Several species became established in Australia and assumed the proportions of weed pests. The two closely-related forms, *O. inermis*, De C., and *O. stricta*, Haw., natives of North America, constituted the main problem, infesting the wooded sub-coastal and mid-inland districts of Queensland and the northern half of New South Wales, all valuable grazing, and to some extent farming, land with an annual rainfall of 20 to 30 inches.

At the peak of the prickly-pear invasion in 1925, the infested territory occupied about 60,000,000 acres, of which approximately 50,000,000 acres were in Queensland.

Roughly one-half of the infested region comprised dense prickly-pear, 3 to 5 feet high, and over very large areas growing so thickly that it presented an almost impenetrable barrier ; the density may be gauged by the fact that the estimated weight of prickly-pear was frequently from 500 to 800 tons per acre. The remaining 50 per cent. of the 60,000,000 acres represented prickly-pear in varying degrees of scattered infestation, and marginal lands subject to periodical development of seedlings.

The heaviest growth occurred on the better type soils, especially in the brigalow (*Acacia harpophylla*, F. v. M.) and belar (*Casuarina cambagei*, Baker) so-called " scrubs," but in reality thick forests. The rate of spread was reliably figured in 1925 at 1,000,000 acres annually, despite the strenuous efforts of the settler and grazier to prevent the overrunning of hitherto pear-free pastures. The very great annual expenditure in the destruction of seedling and scattered plants has never been calculated. The value of natural grazing land, five to twenty-five shillings an acre, renders economically impracticable the eradication of a rapidly spreading weed pest.

Investigations in America.

Biological control of the pest was suggested as early as 1899. The first definite steps were taken in 1912 when the Queensland Government appointed a Travelling Commission to explore possibilities of control ; as a result of its investigations, this Commission recommended the introduction of insect and disease enemies from North and South America.

By mutual arrangement between the Governments of the Commonwealth, New South Wales and Queensland and with funds subscribed by these three Governments, the Commonwealth Prickly-Pear Board was established in 1920, in order to investigate the natural enemies of prickly-pears in America and endeavour to introduce insect and other controlling agents into Australia. The Board's activities are concerned purely with the biological control aspect ; chemical and mechanical control and the administration of prickly-pear lands are the functions of State authorities.

Investigations have been conducted in America without interruption since 1921. Officers of the Board have visited every known prickly-pear region of North and South America, with the exception of Paraguay, portions of southern Brazil, and the Galapagos Islands. Life-history, breeding, testing on economic plants, and the forwarding of insects to Australia have been carried out in the United States from 1921 to 1933, in Mexico from 1926 to 1935, and in Argentina in 1924-25 and from 1931 to 1936. Insect survey explanations have been made in the West Indies, Honduras, Guatemala, San Salvador, Colombia, Venezuela, Brazil, Uruguay, Peru and Ecuador ; the visits to these countries indicated that their cactus fauna did not warrant more detailed investigation, since none of the discovered insects appeared to possess potential value for the control of prickly-pear in Australia.

Attention has been devoted to the fungus and bacterial diseases of prickly-pears. For three years a plant pathological officer conducted investigations in the United States and Bermuda. However, the use of plant diseases did not seem to offer scope for valuable work. Moreover many of the diseases were found to be already established in Australia.

The Board's investigations have resulted in the discovery of approximately 145 different species of insects, the life-histories of which appear to be restricted to prickly-pear and other Cactaceae. Many species have proved new to science. The work was concerned primarily with prickly-pears or Platyopuntias ; passing attention only has been given to other cactus groups, once it had been ascertained that the insect enemies of other cacti were, in general, unable to complete their life-cycle on prickly-pears. A more thorough study of the whole cactus family must have added to the number of species.

In the Lepidoptera, about 56 species have been found, of which about 44 species are included in a related group of several genera in the Pyraloid family PHYCITIDAE. Most forms in this dominant complex are internal feeders in the stems and joints ; a few are purely fruit enemies ; two infest the flowers, while two or three species in the genus *Zophodia* exhibit the peculiar dual habit of being both phytophagous or carnivorous, feeding either in the joints or attacking cochineal, *Dactylopius* spp.

Numerically the Coleoptera follow in importance with about 50 species. The wingless Cerambycid genus *Moneilema* has 26 species and the Curculionid genus *Gerstaeckeria* about ten species (several additional species in this genus have not been recognised during the investigation).

In the Heteroptera about 15 species have been encountered, all except one being in the COREIDAE. There are about 12 Homoptera, the most important group being the soft-bodied scales of the genus *Dactylopius*.

The remaining cactus insects comprise several gall-midges, CECIDOMYIIDAE, two or three LONCHAEIDAE (Diptera), and two phytophagous Chalcidoidea (Hymenoptera).

Not included among the true cactus insects are the many Diptera, chiefly SYRPHIDAE of the genera *Volucella* and *Copestylum*, and STRATIOMYIIDAE of the genus *Hermetia*, whose larvae are associated with injuries caused by primary insects, by plant diseases, or by other means. They are mainly but not solely cactus insects.

In most cases some information has been gathered concerning the life-history and habits of the insects. Many species, those deemed to be of the greater potential value, have been studied intensively.

The Host Restriction Question.

Genera and even groups of genera are restricted to prickly-pears and other cacti. One may instance the various Phycitid genera, *Cactoblastis*, *Melitara*, *Cactobrosis*, *Olyca*, *Ozamia*, etc., the Coleopterous genera *Moneilema*, *Gerstaeckeria* and *Cactophagus*, the Coreid genera *Chelinidea* and *Narnia*, and the Coccid genus *Dactylopius* ; all of these contain several or many species, and all appear truly cactus insects.

The proposal to introduce insect enemies of prickly-pear into Australia immediately raised the question of the potential danger of establishing forms that might transfer their attention to plants other than prickly-pear. The Board has endeavoured to exercise every reasonable precaution in this connection. The host restriction to cactus plants of each kind of insect has been, in so far as possible, proved by field investigation and by information secured from scientific and other sources. The food-plants of other species in the same genus or even in related genera have been ascertained. Finally, each kind of insect has been subjected in America to a series of starvation tests on many plants of economic value, and if these tests were satisfactory, again in Australia before removal from quarantine insectaries. Exhaustive tests have been made on those plants on which feeding was attempted to more than a minor degree.

The value of starvation tests might be doubted. In practice they seem to have had a real value. Inasmuch as they have indicated that the cactus insects could develop in or on other plants, they have pointed to possible dangers. Although certain species were apparently restricted to prickly-pears and did not, on available evidence, attack other plants in their native habitat, their introduction to Australia could not possibly be justified after the tests on other plants had been conducted.

It was at first thought that true cactus insects would not, even under stress of starvation, feed on other plants. Investigation showed, however, that most of the insects could derive in the larval or adult stages some degree of sustenance from certain plants. The important exception to this statement would involve the cochineals, *Dactylopius* spp., which appear to make no attempt to feed on any plant other than *Opuntia*.

If temporary feeding on plants of economic importance had been considered condemnatory evidence, the introduction of most prickly-pear insects could not have been carried out. Hence unless the damage likely to be caused by temporary feeding seemed of a dangerous nature, the positive starvation test has been that the insect must be able to complete the life-cycle on some plant other than prickly-pear.

Botanical relationship has not been the reason for cactus insects feeding or developing on other plants under stress of starvation. Rather, physical conditions somewhat similar to those of prickly-pear appear to have been the governing factor.

In the tests, tomato fruit were prone to be attacked, but not other parts of the tomato plant. The larvae of *Cactoblastis cactorum*, *C. bucyrus*, *Tucumania tapiacola* and other cactus PHYCITIDAE are able to sustain existence for some days, and even to develop to some extent, within tomatoes. They are, however, unable to complete development. Under stress of starvation, both larvae and adults of the Coreid bug, *Chelinidea tabulata*, Burm., will feed on tomatoes, but extensive tests have proved that the larvae cannot complete the life-cycle on these fruit.

The results with certain insects have been very interesting and quite unexpected. The Pyraustine genus *Mimorista*, with at least two species distributed from the United States to Argentine, is limited to Cactaceae. *M. flavidissimalis*, Grote, is prevalent in Texas, Mexico and the West Indies ; the larvae feed on or in the young growth of prickly-pears, and do not attack the flowers, fruit and older cladodes. In confinement, the larvae were reared readily from egg to imago in tomatoes ; moreover, the moths deposited eggs on these fruit.

The Phycitid genus *Ozamia*, distributed from the United States to the Argentine, contains several species, the larvae of which feed in the flower-buds and fruit of *Opuntia*, *Nopalea*, *Cereus*, and probably other cacti. *O. clarefacta*, Dyar, is an important enemy of prickly-pear fruit in Texas, and has not been recorded on other host-plants. In the tests, this insect was bred without difficulty, from egg to adult, on growing peaches.

Obviously, the fact that *Mimorista* and *Ozamia* were able to complete the life-cycle on important economic fruit such as tomatoes and peaches indicated the potential danger of any attempt to utilise them in the control of prickly-pear in Australia. In both genera, the life-cycle is comparatively brief, with four or more generations per annum ; conceivably, they could become pests of fruit. Although both species were deemed to be valuable enemies of prickly-pear, the results of the starvation tests caused their elimination from the programme of introductions.

Another interesting case may be quoted. The Cecidomyiid midge, *Asphondylia opuntiae*, Felt, is a valuable controlling agency in the increase of prickly-pears in the United States and Mexico, since its attack on the fruit prevents the development of the seeds. The life-cycle is singularly adapted to the flowering and fruiting periods of *Opuntia*. It appeared to be a particularly " safe " insect, in that there was little likelihood of development being possible in other fruit. Under close confinement, the midges laid eggs in young apples, peaches, and commercial figs ; the affected fruit soon dried and fell off, and the midge larvae were unable to develop. *Asphondylia* was then discarded from future work. Certainly, the life-cycle had not been completed in the attacked fruit. However it had been shown that the adults would deposit eggs in other fruit, which were destroyed as a result of the act of oviposition. It would have been very difficult to prove that the affected fruit invariably dried out and so prevented the development of the midge larvae.

A final illustration of the precautions exercised by the Board in its introduction work may be cited. The most destructive prickly-pear insects in Mexico and Central America are the three or four species of Calandrid beetles of the genus *Cactophagus*.

In particular, *C. spinolae*, Gyll., is extremely common in Mexico, and lends itself to facile rearing under cage conditions. An officer of the Board conducted a thorough survey in Mexico of the relationship of this insect to plants other than Cactaceae. This investigation showed that with every opportunity to attack other plants, such as banana, sugarcane, maize, and many fruit, vegetable and other crops, *C. spinolae* was restricted to plants of the cactus family. Prickly-pear and *Cereus* hedges surrounding the cultivated plots, and prickly-pear plants growing among plants of economic value, were almost invariably heavily infested with *Cactophagus* ; other plants were not attacked. When the starvation tests were performed, the larvae were able, under certain conditions, to develop in banana fruit. *Cactophagus* is rather closely allied to genera that contain pests of very considerable importance, viz. : *Sphenophorus*, *Rhabdocnemis*, *Cosmopolites*. Hence, it was decided that the introduction of *Cactophagus* into Australia would be fraught with a certain element of risk.

The Australian Organisation.

The headquarters of the Board is situated at Sherwood, a suburb of Brisbane, Queensland. The Sherwood Laboratory is used for introduction, quarantine, supplementary testing on economic plants, and general experiment purposes. Field Stations are maintained at Gogango, 40 miles from Rockhampton, Central Queensland ; at Chinchilla, on the main western railway in South Queensland ; at Goondiwindi in South-west Queensland on the New South Wales border ; and at Scone in the Hunter River Valley, New South Wales. The general breeding and distributional work is carried out at these centres. Moreover, they are so situated that conditions throughout the prickly-pear territory can be constantly observed by means of motor vehicles operating from each field station.

Between 50 and 60 species of cactus insects have been introduced into Australia. In many instances, one or a few consignments were imported for supplementary tests on economic plants or for observations on their behaviour under Australian conditions, and the insects were discarded after trial. In other cases, several or many consignments were received over a period of three or more years. The total number of individual insects introduced from America has reached several hundred thousand. It should be explained that all material from America was used for experimental or for rearing purposes ; it has not been the Board's policy to import insects and to release them directly in the field ; liberations have been effected with Australian cage-reared stocks.

Serious efforts to acclimatise and establish insects have been made with approximately 18 species. In the case of the following insects, the activities are still being continued, and finality has not been reached, viz :

The Phycitid moth-borers, *Melitara prodenialis*, Walker, from Texas, *Cactoblastis bucyrus*, Dyar, from Argentine, *Tucumania tapiacola*, Dyar, from Argentina, and the Cerambycid beetle borer, *Lagochirus funestus*, Thom., from Mexico.

The four moth-borers, *Melitara prodenialis*, Walker, from Florida, *M. dentata*, Grote, from Colorado, *M. bollii*, Zell., from Texas, and *M. doddalis*, Dyar, from West Texas to Arizona, definitely failed to become acclimatised.

Several insects fall into a group that are established in the field in one or more localities, occur in limited numbers and have not become generally dispersed, namely, the Phycitid moth-borer, *Olyca junctolineella*, Hulst, from Texas, the Cerambycid beetle-borers *Moneilema ulkei*, Horn, from Texas, and *M. variolare*, Thoms., from Mexico, and the cochineal, *Dactylopius newsteadi*, Ckll., from the United States ; the host-plant, *Opuntia imbricata*, of the last named insect is found at scattered places only.

Two species became established in the field, but appear to have failed completely in the competition for the food supply with *Cactoblastis cactorum*, Berg. The cochineal, *Dactylopius confusus*, Ckll., from Florida, probably still exists in limited quantity. The Coreid bug, *Chelinidea vittiger*, Uhler, from the United States, had increased to very considerable proportions and was spreading rapidly in 1930–31 ; it has not been seen for almost two years, but may be surviving in very small numbers.

The number of successfully acclimatised insects is very limited, if this category is restricted to those forms that have established themselves throughout the prickly-pear regions. The species are : the Phycitid moth-borer, *Cactoblastis cactorum*, Berg, from the Argentine ; the Coreid bug, *Chelinidea tabulata*, Burm., from Texas ; and the cochineals, *Dactylopius opuntiae*, Ckll. (=*D. tomentosus*, Lam.) from the United States, *D. ceylonicus*, Green (= *D. indicus*, Green) from India and the Argentine, and *Dactylopius* sp. near *confusus*, Ckll., from the Argentine. *D. ceylonicus* is restricted to *Opuntia monacantha* (= *O. vulgaris*), and the unnamed species to *Opuntia aurantiaca* ; *D. ceylonicus* has been introduced on *aurantiaca* but is not yet established on that plant. In this group might be included the Acarid mite, *Tetranychus opuntiae*, Banks.

Very probably some species that were discarded on account either of the results of the testing on economic plants or of their poor potential value, could have been established without difficulty, *e.g.*, *Cactophagus* spp., the *Gerstaeckeria* weevils, *Asphondylia opuntiae*, *Ozamia clarefacta*, *Mimorista flavidissimalis*. Again, efforts to acclimatise an insect complex for *O. inermis* and *O. stricta* were not continued after *Cactoblastis cactorum* had demonstrated its amazing powers.

Progress by Periods.

The Board's original policy was based on the conception that success in the control of prickly-pear by biological means would be accomplished by several or a number of agencies working in harmonious combination. It was thought, too, that progress would necessarily be gradual, in the nature of the thinning out of the dense areas, the complete destruction of plants here and there, the reduction of fruiting and hence of the rate of spread. It was not anticipated that the outstanding success would be brought about by one insect within the short space of a few years.

The progress of the investigation may be stated in the following rough chronological order :—

1921–25 :	The insect complex period, when various species were introduced. *Olyca junctolineella*, *Chelinidea tabulata*, *C. vittiger* and *Dactylopius opuntiae* were reared in large numbers and were established in the field.
1925–27 :	Introduction of *Cactoblastis cactorum*, its large scale rearing and first liberations.
1928–30 :	The mass distribution of *C. cactorum* throughout the pear areas, when approximately 3,000,000,000 insects were released.
1930–32 :	The collapse and destruction of prickly-pear, brought about by an enormous population of *C. cactorum*.
1931–33 :	Recurring growth and seedling development gave cause for some anxiety. In most districts, with the destruction of the original pear *Cactoblastis* was left without a food supply and suddenly diminished to a small population.
1933–35 :	The control of regrowth and seedling pear by *Cactoblastis* ; the development of former pear lands.

In 1929, when *Cactoblastis* commenced its onslaught, *Chelinidea tabulata*, Burm., was in enormous numbers throughout the pear country ; *C. vittiger*, Uhler, was well established and was increasing fast ; *Dactylopius opuntiae*, Ckll., was everywhere, one might say on every prickly-pear plant ; *Tetranychus opuntiae*, Banks, infestation was heavy and was quickly becoming general ; and *Olyca junctolineella*, Hulst, was established in several districts.

What has happened to these insects ? The destruction of prickly-pear by *Cactoblastis* has been so rapid that in the competition for the food supply they have gone to the wall. *Chelinidea tabulata* survives in small numbers ; its former heavy concentrations exist no longer. *C. vittiger* has disappeared completely. *Olyca junctolineella* manages to maintain existence in one or two localities ; in most places it too has disappeared. *Tetranychus* occurs spasmodically ; the spectacle of larger areas of prickly-pear covered with the greyish corky layer resulting from its attack is never encountered. Cochineal, *Dactylopius opuntiae*, alone has been able to continue its existence on a moderately efficient scale, probably on account of the fact that its life-cycle is shorter and its reproductive rate greater than that of *Cactoblastis*.

One might conjecture with regard to the present situation in prickly-pear control, had *Cactoblastis* not been brought into the picture. There is little doubt that the original anticipations would have been realised. The insects named above had, by 1929, very clearly indicated that they could be expected to thin out the dense areas, kill individual plants, devitalise the plants and reduce the normal fruit crop, destroy the immature fruit and so lessen the tremendous yearly increase of the pest. But these beneficial effects would have been gradual.

Cactoblastis cactorum in the Control of Prickly-Pear.

Cactoblastis cactorum, Berg, is a native of Uruguay and the northern Argentine provinces of Entre Rios, Corrientes, Santa Fe, Santiago del Estero, Tucuman, Salta, and the Chaco ; possibly its range extends northwards into Paraguay and southern Brazil. It is prevalent throughout the named regions, whose annual rainfall varies from 20 inches in Santiago del Estero to 60 inches in Corrientes ; the whole area of distribution is essentially summer rainfall territory. The host-plants comprise various *Opuntia* of divergent types, including several species of the *monacantha* group, *e.g.*, *O. bonaerensis*, Speg., and *O. delaetiana*, Web. ; low-growing narrow-jointed species of the *aurantiaca* series, such as *O. aurantiaca*, Lind., *O. discolor*, Brit. & Rose, and *O. utkilio*, Speg. ; the upright slender-jointed *O. salmiana*, Parm. ; and the large prickly-pears, *O. quimilo*, Schum., *O. cordobensis*, Speg., *O. brunnescens*, Brit. & Rose, and *O. ficus-indica*, Miller.

C. cactorum is a gregarious internal-feeding Phycitid. The greyish-brown moth has a wing expanse of 1–1·5 inches. In common with many other cactus Phycitids, the females deposit the eggs in long chains, termed " egg-sticks," the first egg being attached to a spine or spicule on the plant. The egg-sticks may contain as many as 120 eggs (an extreme number of 150 has been recorded), but the average is about 75 eggs per stick. The larvae are bright orange-red, with transverse rows of black spots which almost coalesce and give the effect of black cross-bands. The loose white silky cocoons are usually formed among rubbish near the base of the attacked plant. There are two generations annually, a shorter summer generation of four months, and a longer winter generation occupying eight months ; the winter is passed in the larval stage.

A closely-related species, *C. bucyrus*, Dyar, with similar habits, occurs in the drier sections of western Argentina.

The only introduction of this insect consisted of approximately 2,750 insects forwarded as unhatched eggs from the Argentine in March 1925 ; actually 3,000 eggs were despatched, but at Cape Town the South African authorities removed two or three colonies of larvae, as a precautionary measure in the event of disaster overtaking the larvae during the remainder of the voyage. The parent stock of this material was collected as larvae at Concordia, province of Entre Rios, Argentina, in February 1925, and the moths emerged and oviposited at Buenos Aires. The consignment was received at Sherwood, Brisbane, in May 1925, the larvae being by then approximately half grown. They developed steadily during the winter, and as the Argentine food supply, an undetermined relation of *O. monacantha*, was exhausted, transferred readily into *O. inermis*. 1,137 cocoons were obtained in August–September, which produced 1,070 moths in September; 527 females, almost 50 per cent. of the total moths, deposited 100,605 eggs, an average of 191 eggs per female. An increase of 35-fold in the first generation was a happy augury for the future.

The total number of 100,600 eggs was used for rearing purposes at Sherwood and the Chinchilla Field Station. The cages gave a return of 42,071 moths in January–February 1926, and 19,005 females deposited 2,539,500 eggs. Thus, in two generations over a twelve months' period, the original stock of 2,750 eggs increased by more than 900 times. At this stage the first liberations were made with a total of 2,263,000 eggs divided between 19 different localities, representative of varying conditions throughout the prickly-pear territory.

Rearing work was continued for a further twelve months, during which period an additional 6,500,000 eggs were released at many field localities.

The establishment of the original liberations was, in most cases, apparent within twelve months. Early in 1927, after the completion of two generations in the field, many prickly-pear plants had been killed, and the insects had increased to such an extent that further rearing in cages was not required. These liberations now formed the bases from which supplies could be secured for general distribution.

Two years after the first material was placed in the field, *C. cactorum* had multiplied enormously at various centres; already, hundreds of acres of dense prickly-pear had collapsed, and the insect had dispersed for a distance of several miles from the liberation points.

The value of *Cactoblastis* having now been demonstrated, mass distribution was carried out during the period 1928 to 1930, in a co-operative campaign between the Board, the Queensland Prickly-Pear Land Commission and the New South Wales Department of Agriculture, with the additional assistance of landowners. In order to secure the eggs required for distribution, cocoons were collected in large numbers from field centres; the moths emerged and oviposited in the cages, and the eggs were gathered daily. By this method 400,000,000 eggs were made available in 1928-29. But *Cactoblastis* increased so rapidly that in 1929–30 eggs were deposited in enormous numbers in areas where establishment was first effected. In these two years, the vast quantity of 2,350,000,000 eggs was gathered direct from the plants in the field for general distribution.

The eggs were gummed on squares of paper, or were placed in paper quills, which were pinned to the prickly-bear cladodes. Motor lorries with gangs of men distributed the eggs on all trafficable roads. Large numbers were supplied free of cost to landowners. The establishment of *Cactoblastis* throughout the whole of the infested country was virtually completed within six years after its introduction into Australia.

The Manner of Destruction.

Prickly-pear is a succulent plant which contains 90 per cent. water. Its susceptibility to an efficient tunnelling insect is very pronounced. The social habit of *C. cactorum* of living in colonies containing twenty or more larvae is of paramount importance. Solitary tunnelling larvae, such as *Olyca junctolineella*, do not cause effective injury; the injured cladodes tend to heal rapidly.

The larvae of *Cactoblastis* devour the whole of the cladodes, except the vascular bundles and the thin papery cuticle, and the injured segments dry out. More often, however, the tunnelling of the larvae sets up conditions favourable for plant diseases, bacterial in the more terminal growth, fungus infections in the thicker lower portions; in consequence, destruction is hastened.

In young plants and in larger plants of the most succulent type, the larvae burrow into the lower stems, even to below ground-level. But large plants are completely destroyed, although the larvae have not entered the lower stems. Apparently, the concentrated attack of many, often thousands, of larvae in all except the lower stems causes a physiological breakdown of the basal portions, various fungi being associated with and probably assisting the decay. One might emphasise the point that no specific plant disease accompanies or follows the larvae. Furthermore, destruction of plants is not accomplished unless the larval population is heavy. Bacterial soft rots are active in the more succulent growth infested with the larvae when climatic conditions are suitable; definitely they are not responsible for the disintegration of the lower stems.

The first concentrated onslaught by *Cactoblastis* may suffice to bring about the collapse of the more succulent forms of *inermis* and *stricta* especially in the brigalow and belar " scrubs." But in the harder types, the more terminal growth is destroyed, while the thicker segments and stems are little damaged; indeed the larvae are unable to sustain existence in the main branches of certain vigorous growing " resistant " forms. These plants then produce a great amount of new growth, sufficient to support a second larval population. After two or three waves of attack, the plants usually collapse rather suddenly, as if their powers of resistance have been expended. One might state that if the initial attack by *Cactoblastis* merely damages the plant, new growth must be produced before it is destroyed.

Subsequent to the establishment of *C. cactorum* at any point, destruction has not followed in the way of a plant here and there, but has radiated outward from the centre, for the reason that although the moths are free-flying and do disperse for considerable distances, the great majority of the eggs are deposited on the plants nearest to those inhabited by the preceding generation of larvae. This instinct of the females to oviposit in the immediate vicinity of their point of emergence from the cocoons is responsible for the spectacle of whole areas of prickly pear being destroyed simultaneously.

After the completion of the mass distribution campaign, *Cactoblastis* increased to vast numbers very quickly. The general breakdown of prickly-pear soon followed, and by the end of 1933 practically the whole of the primary pear in Queensland and the north-west areas of New South Wales had collapsed, with the exception of relatively small areas here and there and the " yellow " *inermis* of certain districts in New South Wales.

The celerity with which flourishing prickly-pear was reduced to a rotting mass of pulp was indeed remarkable. One example will serve as an illustration. Along the Moonie River in south-west Queensland, dense prickly-pear extended in an almost continuous belt for 100 miles, through which the old Dalby-St. George coach route wended a narrow laneway. Distribution of *Cactoblastis* was conducted in this region in 1929. In August 1930, no destruction had been brought about, and the establishment of *Cactoblastis* was so light that further distribution was given serious consideration. Yet in August 1932, 90 per cent. of this huge area of prickly-pear had been destroyed.

The Regrowth Question.

Prickly-pear is a virile plant, with a tenacious hold on life. Detached joints or pieces of joints in contact with the ground soon take root and grow. Plants, which had almost completely decayed, spring up quickly from small portions of sound tissue.

The destruction of the primary pear by *Cactoblastis* did not signify its eradication, since the butts had not disintegrated. Recurring growth soon appeared and grew rapidly. With the wholesale collapse of the primary pear, the *Cactoblastis* population of an area or district was suddenly decimated through starvation, and insufficient insects survived to check the quickly-developing secondary growth.

For the first year or two of *Cactoblastis* progress, regrowth was soon controlled. The areas of destruction were restricted ; the infestation of the insect in the adjacent green pear was heavy, and the moths laid eggs freely on the recurring growth. But when large tracts of prickly-pear were destroyed in the space of a few months, and *Cactoblastis* starved to death in untold millions, regrowth flourished.

The vigour of the regrowth varied. In the true belar (*Casuarina cambagei*) " scrubs," where the original pear reached its maximum density, regrowth, for some unexplained reason has not in any instance appeared other than as scattered joints. On the other hand brigalow (*Acacia harpophylla*) scrubs have usually produced heavy regrowth. The more open Eucalyptus forests of the better type soils have favoured vigorous recurring growth. In many instances the regrowth within two years almost reached the formidable proportions of the original pear.

In the years 1931–33, regrowth in varying degrees of density had taken the place of the primary pear in most districts. Strange to relate, in Central Queensland there has been no big wave of secondary growth ; here and there, heavy patches have become evident, but generally the destruction of the original pear has been followed by nothing more serious than scattered new growth.

As soon as the regrowth position commenced to assume importance, the Board decided, in June 1931, that it might be unwise to depend on *Cactoblastis* for its control and set out to make a special overseas search for insects that would destroy young growth or might be expected to destroy the basal portions of prickly-pear. Studies with *Mimorista flavidissimalis* and *Cactophagus* spp. were discontinued on account of the results of the starvation tests on economic plants. The cochineal, *Dactylopius confusus*, from Florida and further material of *D. opuntiae* were introduced without accomplishing any useful results.

However, in 1933, it was obvious that *C. cactorum* would triumph over regrowth as it had over the original pear. Actually the insect multiplied from small to very great numbers much faster than in the primary pear. Recurring growth is more easily destroyed by insects than well-established plants. It is a forced, succulent development that does not possess the qualities of " resistance " characteristic of primary pear. In so far as *Cactoblastis* is concerned, in regrowth the mortality in the larval stages is lower, the larvae are larger, and they produce larger moths with a greater fecundity than the average moth from primary pear.

Two illustrations of regrowth control will serve to show the recovery of *Cactoblastis*. The Wandoan-Taroom district of southern Queensland was, in December 1932, a compact mass, approximately 50 miles square of vigorous secondary growth, in which colonies of larvae were well distributed but were not causing appreciable damage. In the June 1934, eighteen months later, 90 per cent. of the pear had been destroyed.

Around Mungindi, in north-west New South Wales, the original pear, growing partly in belar scrubs and partly in open or lightly timbered country, succumbed in 1930-31. As in other cases, the destruction in the belar scrubs was final. Elsewhere, a strong regrowth reached, in August 1933, a height and density little inferior to the original infestation ; *Cactoblastis* colonies were extremely scarce, averaging less than one colony to one hundred pear plants. Yet in August, 1935, all this growth had been destroyed. In order to have achieved this result, the numbers of larvae must have increased by not less than 5,000 times within two years.

Regrowth is now under control. Over by far the greater part of the pear territory it is restricted to scattered joints or pieces of two or three joints. In most districts occur at intervals relatively limited areas of regrowth, which has persisted for eighteen months to two years. In a few localities another wave of recurring growth has made its appearance to some extent during the current summer.

It should be emphasised that re-distribution of *Cactoblastis* has not been found necessary. The insect has not died out in any locality. Its capacity to multiply from greatly reduced to enormous numbers when a nutritient and abundant food-supply was available has been an outstanding feature of its control of secondary growth. Wherever regrowth, even of a very scattered character occurs, colonies of larvae can be observed.

One might ask whether the same set of circumstances may not be repeated more or less indefinitely, namely, waves of destruction followed by waves of recurring growth. It is, however, unlikely that future developments of regrowth will reach the proportions of 1931–33.

In the course of the destruction of the primary growth the prickly-pear collapsed completely and rather suddenly over very extensive areas ; in consequence *Cactoblastis* almost disappeared from the scene. In the case of regrowth destruction, although most of the prickly-pear was destroyed in a comparatively short period once the insect's population reached a certain degree of concentration, some areas were partly damaged only and remained to serve as breeding-grounds. This experience has been common to most districts. Furthermore, the first wave of secondary growth is much more vigorous than later recurrences, for the reason that its destruction brings about the eradication of many butts and roots.

The Seedling Pear Question.

The seedling pear problem, as discussed in this article, is considered to involve the development of prickly-pear on pastures that did not support a heavy body of pear prior to 1925. The former rapid spread and increase of the pest resulted from the enormous fruit production, the eating of the fruit by birds and animals, and the consequent dispersal of the seeds. In the pre-*Cactoblastis* period, pastures adjacent to dense prickly-pear were, if left undisturbed, overrun with the pest and were rendered useless for grazing purposes within a few years. The prickly-pear was kept in check on these fringing lands by yearly poisoning or otherwise destroying the young plants.

Shortly after *Cactoblastis* commenced its destructive progress, the poisoning of scattered pear largely ceased, and control was left to the insect. This meant a very great saving in effort and expenditure.

Prickly-pear seeds are viable for 15 years, possibly longer. Thus, scattered plants have continued to appear on " clean " areas. Often they have temporarily escaped the attentions of *Cactoblastis* and have reached fruiting age in three or four years, before they have been brought under control. On the whole, *Cactoblastis* has been as efficient in destroying scattered prickly-pear as in dealing with the dense infestations.

In a few cases, mainly in south-west Queensland and adjacent north-west New South Wales, pastures became densely infested with prickly-pear in the period 1930-33. Naturally the overrunning of land that had hitherto been maintained free from the pest gave rise to a certain amount of concern. The present position with regard to seedling pear is analogous to that of regrowth. In general, *Cactoblastis* has destroyed most of the scattered pear that has made its appearance since 1930. Some plants persist ; new plants continue to appear. As a precautionary measure, in order that scattered pear on clean pastures may not disseminate seed too freely, the State authorities carry out, or insist upon, the poisoning of plants of fruiting age in certain areas.

The Yellow Pear Question.

There are two districts in which the control and eradication of prickly-pear has not reached the stage of advancement so pronounced in the pear territory generally. The most southerly large tract of *O. inermis* occurs in the Hunter River watershed in New South Wales ; the prickly-pear is found mainly on timbered ridges of rather poor soil, the valley lands having been maintained clean on account of their agricultural and grazing value. The second district comprises the hilly Eucalyptus-timbered section of the Inverell-Bingara-Warialda country in northern New South Wales.

The mean annual temperature of these districts lies between 60 and 64 degrees Fahr., in comparison with 66 to 69 deg. Fahr. in the north-western and western pear areas of New South Wales. The cooler conditions affect the development of *Cactoblastis*, and the generations are late. In the winter generation the larvae are small to less than one-half grown at the end of May and must continue to develop during the coldest months. In normal circumstances the larvae are at least two-thirds grown at the end of May, and feed very slowly during June and July. Thus, to some extent, these districts are outside the most effective climatic range of the insect.

But the main cause of the slower progress of *C. cactorum* is found in the prickly-pear itself. The *O. inermis* of these sections is chiefly what is commonly termed " Yellow Pear." Yellow pear is a slow-growing chlorotic plant, which yields relatively few fruit and little succulent growth ; its nitrogen content is less than one-half that of normal green pear ; it is essentially a product of inferior soils. An application of a nitrogenous fertiliser stimulates growth and alters the chlorotic appearance.

Investigations have proved that *C. cactorum* is unable to increase rapidly in yellow pear because the larval mortality is very high. The explanation of the low survival rate is undoubtedly the low nitrogen content. Large scale experiments were conducted at Scone, New South Wales, on growing yellow pear and normal green pear during three *Cactoblastis* generations ; the average larval survival rate per generation was 8 per cent. in yellow pear, compared with 33 per cent. in green pear ; the average increase per generation was not higher than 79 per cent. in yellow pear, in comparison with 1,209 per cent. in green pear. Thus the increase was 15 times as great on normal *inermis* as on chlorotic *inermis*.

Typical yellow pear, given a prior application of a nitrogenous fertiliser, sufficient to turn the plants green without stimulating new growth, was used in one series of rearing experiments. The larval survival rate was 9·5 per cent. in yellow pear, compared with 26·1 per cent., in the treated pear ; the generation increase was 221 per cent. in yellow pear, 1,108 per cent. in the treated pear.

Of course, the use of artificial stimulants for large areas of yellow pear is impracticable. However, there is a simple remedy. In the competition for the available food supply in the soil, the trees take the bulk of the nitrogen. When the timber is destroyed, the yellow pear soon becomes a normal green free-growing plant, suitable to the requirements of *Cactoblastis*.

A policy of timber destruction is practised by landowners in the Inverell-Bingara district. The results have, within three years, fully justified the effort. Wherever the trees have been killed, the prickly-pear has been severely damaged and destroyed to a considerable degree. In the unimproved timbered country, little evidence of destruction is apparent. It should be remarked that the land has a very poor grazing value until the timber has been destroyed.

Although *Cactoblastis* was liberated in large numbers in the Hunter River district concurrently with the distribution in other prickly-pear areas, its establishment was very sporadic and had caused no marked injury until the end of 1931. Since that year it has progressed steadily. To-day, fully 60 per cent. of the original prickly-pear has been destroyed. Regrowth occurs to some extent, but injured yellow *inermis* does not yield the virile secondary growth characteristic of the more succulent types of the plant.

Prickly-Pears of Lesser Importance.

In addition to *O. inermis* and *O. stricta*, three species of prickly-pear have assumed pest dimensions, viz.: the velvety tree-pear, *Opuntia tomentosa*, Salm-Dyck, the white-spined semi-tree-pear, *O. streptacantha*, Lem., and the low-growing narrow-jointed tiger-pear, *O. aurantiaca*, Lind. The Board's first consideration was the control of the main prickly-pear pest, but at the same time the insects introduced for *O. inermis* and *O. stricta* were experimented with on other species. Once success in the biological campaign against the major problem was in sight, and the failure of *Cactoblastis* to bring about satisfactory control of the lesser pest pears was established, greater attention has been focussed on the insect enemies of the latter.

Opuntia aurantiaca, a native of Uruguay and north-eastern Argentina, occurs in a great many places in southern Queensland and New South Wales. There are no very extensive areas of this plant but it continues to spread, despite energetic poisoning methods employed by the State prickly-pear authorities. *C. cactorum* attacks tiger-pear freely, and destroys the growth, but it does not usually penetrate into or cause the rotting of the underground bulbs. In a large clump of *aurantiaca* there are scores of the hard bulbs, which produce new shoots in profusion. Growth is very rapid; hence the destruction by *Cactoblastis* is mainly transient.

Realising the danger of the spread of tiger-pear, which, moreover, is a serious pest in South Africa, the Board conducted a special investigation of its insect enemies in the Argentine in 1931–1935, with the result that one promising insect has been established in Australia. The cochineal, *Dactylopius* sp. near *confusus*, Ckll., has increased very quickly since its introduction in December 1932, and is now effecting considerable damage to *aurantiaca* in several localities. Another insect, the Phycitid moth-borer, *Tucumania tapiacola*, Dyar, was imported in 1935, and is now being reared and liberated.

The tree-pears *O. tomentosa* and *O. streptacantha* are found in central Queensland. There are extensive scrubs of the former, several comparatively large areas of the latter, and a good deal of scattered infestation of both species. Young plants are sometimes eradicated by *Cactoblastis* which otherwise is not an efficient enemy.

The cochineal, *Dactylopius opuntiae*, Ckll., introduced for *O. inermis* and *O. stricta* control, does effective work in thinning out the dense scrubs of *O. tomentosa*, but is not destructive to the scattered plants. *O. streptacantha* was immune to cochineal attack until a special strain of *D. opuntiae* was imported from Mexico; the insect is now proving of value in reducing the density of the heavier infestations. The Cerambycid beetle-borer, *Moneilema ulkei*, Horn, offers prospects of gradual eradication of *streptacantha*. Recently another Cerambycid, *Lagochirus funestus*, Thoms., which seems to possess greater potentialities, has been introduced with the object of destroying tree-pears.

The Future of Cactoblastis cactorum, Berg.

The continued control of prickly-pear in Australia depends upon the continued efficacy of *Cactoblastis*. In the major pear areas the insect's population is a mere fraction of the vast numbers extant at its zenith, purely for the reason that an abundant food supply no longer exists. Its rate of increase and its destructive powers have not waned. Nor, too, has a real danger from outside influences made an appearance. Diseases and insect enemies take a certain toll and may be discussed briefly.

Diseases.

Although fungus and bacterial infection may be found among the larvae and pupae in most localities, the mortality from disease factors is normally so slight that it may be dismissed as of no importance.

However, during the period 1929–32, when vast numbers of larvae were attacking and destroying the original prickly-pears, disease epidemics caused very great losses over wide areas in many districts, chiefly in the autumn, April–May, and spring, August–September. Since 1932, there have been no epidemics ; occasionally a local outbreak, very limited in extent, has occurred.

Diseases become rampant when the larval population is crowded and the food supply is unsatisfactory. Thus, when the larvae were in very great abundance in rapidly collapsing primary pear, the supply of succulent growth was soon exhausted, the larvae were crowded in the lower joints, and conditions favourable to disease increase were set up.

No epidemic has been recorded among heavy concentrations of the larvae in regrowth, which offers adequate nutrition for their development. Indeed, in the case of the heavy mortality in primary pear in 1929–32, it would have been impossible to estimate to what extent diseases were responsible since, without doubt, unsuitable food conditions alone would have caused a considerable death-roll. Furthermore, the seriousness of disease outbreaks is more apparent than real ; in most instances the epidemic destroyed the congregated larvae that would have succumbed later to starvation.

Natural Enemies.

The only enemies worthy of discussion are two species of pupal parasites of the genus *Stomatoceras* (Hymenoptera, CHALCIDIDAE). These indigenous insects have attacked all species of cactus Phycitids introduced into Australia, and were reared from pupae of *Olyca junctolineella*, Hulst, as early as 1923.

Stomatoceras exercise a definite, if not an important, degree of control. A very large amount of data has been collected on their controlling effect over a period of several years ; furthermore, the life-history and ecology of the two species have been investigated very comprehensively.

Allowing for seasonal and generational fluctuations, the average proportion of *Cactoblastis* pupae destroyed by these parasites annually is at the present juncture considered to be approximately as follows :—

Central Queensland	10 per cent.
South Queensland	12 ,,
South-west Queensland and adjacent area in New South Wales	8 ,,
The Moree-Bingara country, New South Wales	14 ,,
Hunter Valley, New South Wales	22 ,,

These figures give the actual proportion of attacked pupae. They do not represent the real degree of control exercised, since there is always a definite, although variable, mortality among the pupae from general causes. The non-parasitic mortality generally ranges from 10 to 30 per cent. Hence, the real effect of *Stomatoceras* on the increase of *C. cactorum* can, on the above figures, be enlarged as under :—

Central Queensland	13 per cent.
South Queensland	16 ,,
South-west Queensland, etc.	11 ,,
Moree-Bingara district	19 ,,
Hunter Valley	30 ,,

In South and South-west Queensland parasitism has increased in the last three years ; in the other districts it has remained more or less stationary. For example, the 1935 figures from the Hunter Valley were not higher than in 1930.

All available information leads to the deduction that the mortality among *Cactoblastis* pupae through *Stomatoceras* attack will not increase beyond a maximum of about 25 per cent. The reasons for this belief cannot be discussed at length in this paper, but a few factors favouring the host may be given :—

(*a*) A considerable proportion of the pupae are not accessible to *Stomatoceras* ;

(*b*) The potential rate of increase is greater in *Cactoblastis* than in *Stomatoceras* ;

(*c*) *Stomatoceras* are adversely affected by climatic influences to a much greater degree than *Cactoblastis*, *i.e.*, the survival rate of the host is greater than that of its parasite.

The Reclamation of Prickly-Pear Lands.

In Queensland, 16,000,000 acres, formerly heavy prickly-pear land, have been made available by the State Land Authorities for occupancy under developmental conditions. As virtually the whole of this area was moderately to heavily timbered, considerable improvements must be effected before the reclaimed country is brought to full productivity, either for grazing, dairying or agricultural purposes.

The developmental work includes the destruction of the standing trees, the erection of fences, and the provision of water for stock by means of dams and catchment tanks. Great progress has been accomplished in the past five years and the activities are being continued energetically.

The greatest proportion of the recaptured area will be used purely for sheep and cattle grazing. Certain districts are suitable for the fattening of beef cattle. Some sections, owing to the richness of the soil and their closer relation to population and markets, are adaptable for division into smaller areas for dairying and farming or for a combination of these two purposes ; these districts include the Dawson Valley, the Burnett River country, the Chinchilla and the Milmerran country. Artificial grasses for dairy cattle and crops such as wheat, maize and cotton are being grown successfully.

From a reclamation viewpoint, the Chinchilla district, 180-200 miles west of Brisbane, affords the best example at present of the settlement of former dense prickly-pear country. Widespread destruction by *Cactoblastis* was brought about earlier than in other centres ; most of the land is of good quality, with a preponderance of brigalow and belar scrub types. New roads, giving access to the railway, criss-cross the former scrubs. Settlers' homes, newly-built, are dotted here and there. Most of the timber has been destroyed and replaced by planted grasses, feeding herds of good quality dairy cattle. Cultivation paddocks and crops occur at intervals. The township of Chinchilla has made considerable growth, a new butter factory is operating to full capacity, and smaller settlements along the railway are expanding.

The north-western districts of New South Wales did not possess the extensive tracts of dense prickly-pear characteristic of Queensland. Owing to the distance from markets, closer settlement of reclaimed land has not been feasible. Much pear country was included in pastoral holdings, and much was embraced in State forests. Sections have been subdivided and granted as additional areas to settlers holding adjacent country. The pear-freed lands will be utilised mainly for wool growing, but smaller areas lying east from Moree lend themselves to combined sheep grazing and wheat cultivation. As in Queensland, the destruction of the standing timber is evidence of progress.

EXPLANATION OF PLATE XV.

Fig. 1.—Typical dense *Opuntia inermis* in brigalow and belar scrub prior to attack by prickly-pear insects ; Chinchilla, Queensland, October 1926.

Fig. 2.—The same view taken in October 1929, showing the destruction caused by *Cactoblastis cactorum*, Berg.

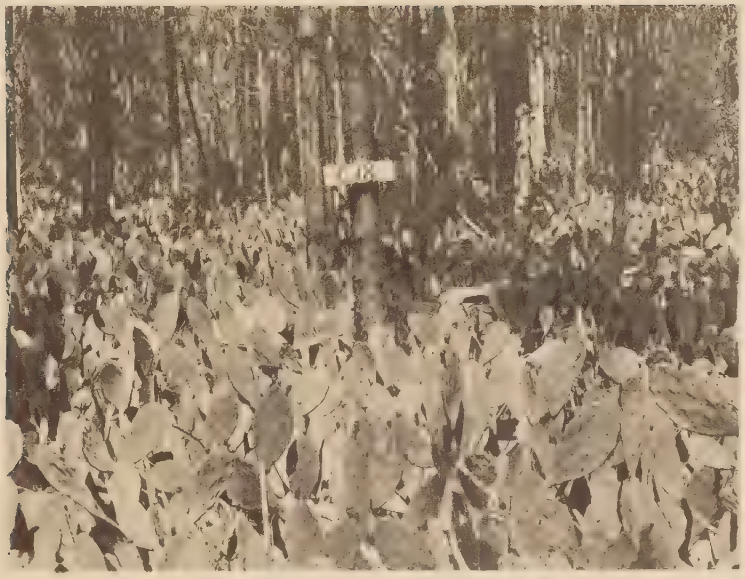

Fig. 1.

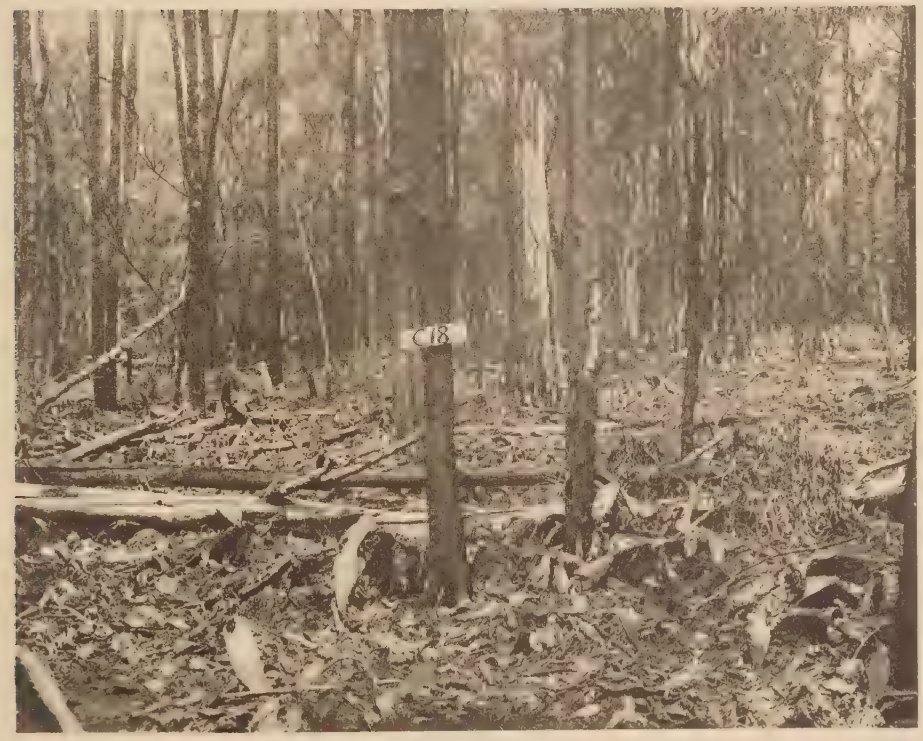

Fig. 2.

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CONTROL OF PRICKLY-PEAR IN AUSTRALIA.

Explanation of Plate XVI.

Fig. 1.—The same view taken in December 1931 ; the timber has been felled and burnt and the area planted with Rhodes grass (*Chloris*) for the purpose of grazing dairy cattle.

Fig. 2.—A new settler's home and improvements near Chinchilla, Queensland, in May 1932 ; the whole scene was dense prickly-pear in 1927 and was reclaimed through the agency of *Cactoblastis*.

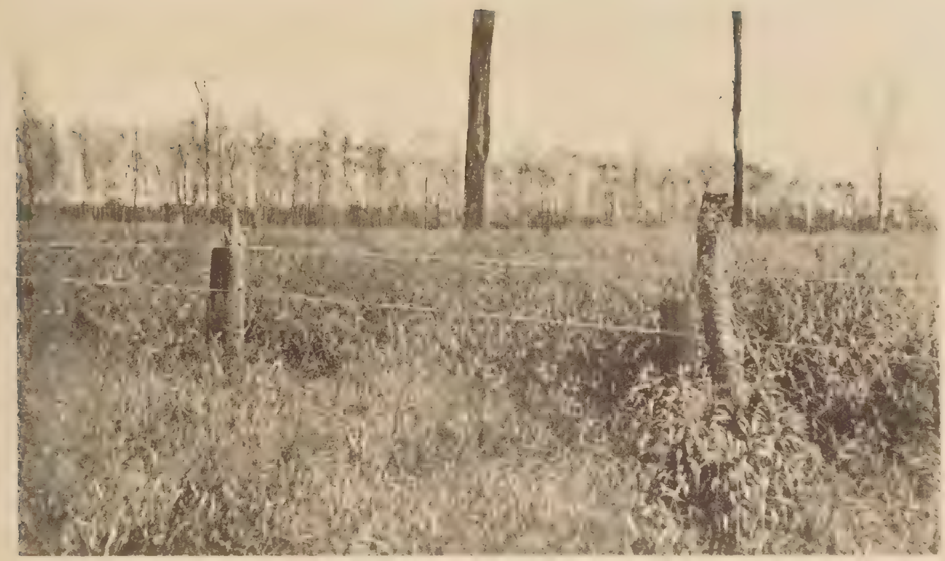

Fig. 1

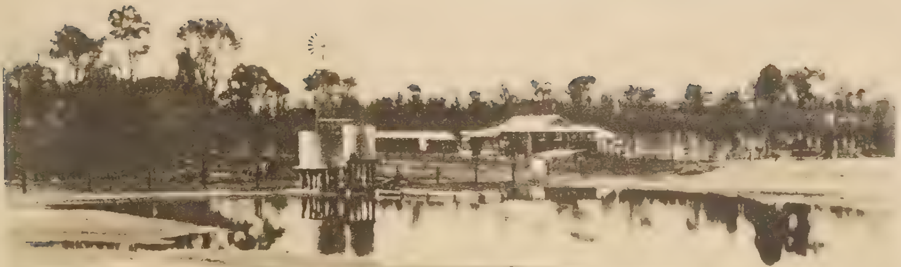

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Fig. 2.

CONTROL OF PRICKLY-PEAR IN AUSTRALIA.

Explanation of Plate XVII.

Fig. 1.—Secondary growth of *O. inermis* in November 1930, following the destruction of the original prickly-pear by *Cactoblastis* in 1928.

Fig. 2.—Numerous " eggsticks " of *Cactoblastis cactorum* on a small plant of *Opuntia inermis*.

Fig. 3.—*Dactylopius* sp. near *confusus*, attacking *Opuntia aurantiaca*, Warwick, Queensland, March 1936.

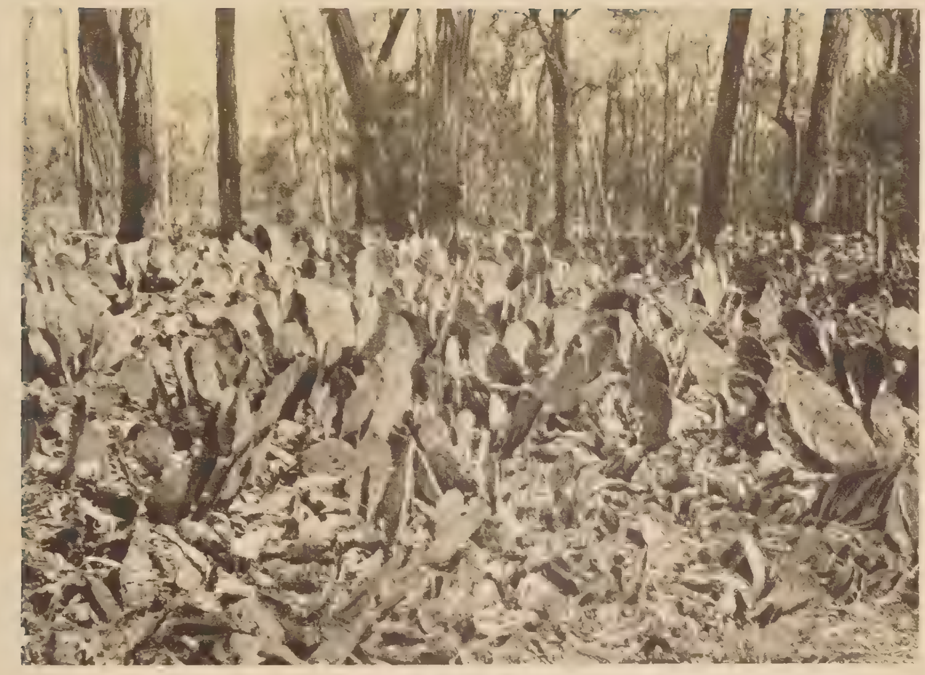

Fig. 1

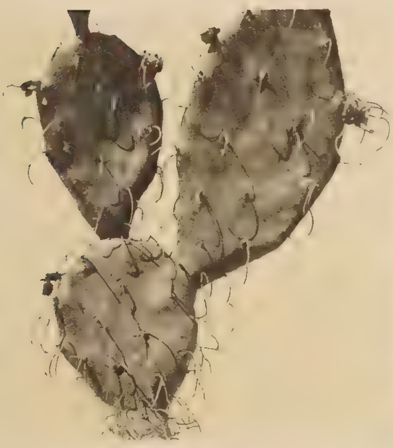

Fig. 2.

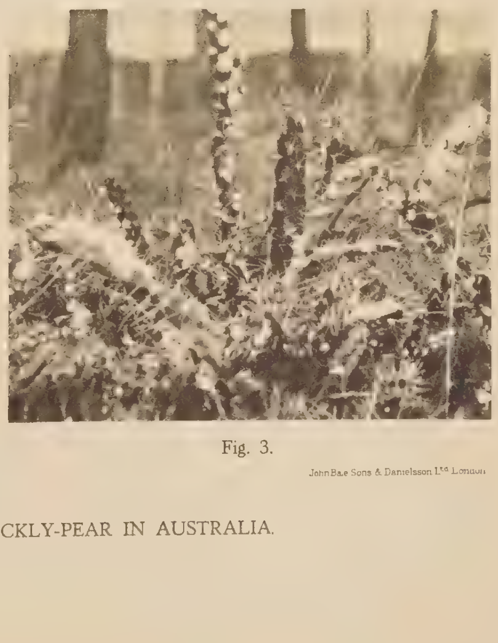

Fig. 3.

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CONTROL OF PRICKLY-PEAR IN AUSTRALIA.

ANNOTATED LIST OF INSECTS INJURIOUS TO COTTON IN TANGANYIKA.

By W. Victor Harris, M.Sc., F.R.E.S., F.Z.S.,

Department of Agriculture, Tanganyika Territory.

The cotton plant in Tanganyika is the host of a large variety of insects, but the greater part of the damage is done by only a few species. Nevertheless a considerable number of species must be looked on as potential pests, even though they are at present difficult to find. An example of this is the Capsid bug, *Helopeltis bergrothi*, which prior to 1935 was nothing more than an interesting record on cotton quite difficult to find on that crop. In that year, however, it appeared in numbers in quite widely separated districts, achieving the status of a minor pest.

The cotton-growing areas of Tanganyika fall naturally into two widely separated zones, an eastern or coastal zone stretching some two hundred miles inland from the Indian Ocean, from sea-level to an elevation of 2,500 feet, and a western zone south from Lake Victoria, at approximately 4,000 feet. Small areas of an experimental nature have been or are at present under cotton and do not fall into these zones. Such areas are interesting from a pest point of view, as, for example, when cotton was grown in Songea, on our southern border, the only record of *Diparopsis castanea* was obtained there. Since cotton is no longer grown there, this insect, which is so important in other countries, does not rank even as a minor pest. The chief difference in the pest fauna of the two zones is the absence of pink bollworm in the western zone. This and similar matters are being discussed elsewhere.

The pests are grouped here according to the part of the plant usually attacked by them. Within each group they are arranged in the usual systematic order. A rough indication of the present status of each insect is given as follows :—

** Major pest—of primary importance in the area of its occurrence.

* Minor pest—definitely injurious but of restricted occurrence, or never in great numbers.

No asterisk indicates that the injury is not likely to cause appreciable loss of crop.

With few exceptions the identification of the insects has been made by the Imperial Institute of Entomology, to whom we would again express our appreciation.

1. Insects Injurious to Seedlings.

Gryllidae.

Liogryllus bimaculatus, De G. ; *L. morio*, *F*. Two pests of seedlings generally, not of major importance.

Curculionidae.

Goniorrhinus terrenus, Mshl. A small weevil attacking the cotyledons, known only from a single estate in the Kilosa district.

2. Insects attacking Stems and Branches.

Termitidae.

Microcerotermes parvus, Hav. A common soil termite which tunnels into the stem *via* the roots and causes the plant to wilt and die.

***Microtermes* sp. A soil termite causing much damage in parts of the west by boring into the stem or ring-barking at soil-level.

LAMIIDAE.

**Tragiscoschema nigroscriptum*, Fairm. A long-horned beetle which rings the stem, lays an egg there, and the resultant larva completes the damage. A spasmodic pest.

CURCULIONIDAE.

Alcides brevirostris, Boh. A weevil girdler whose work is distinguished from that of *Tragiscoschema* by the presence of fuzz around the injury. Less common than the above.

***Apion xanthostylum*, Wagn. A small black weevil which bores into the collar and the nodes. The grubs develop in the stem or branches and the plant wilts and breaks at the affected spot. Restricted to Morogoro, where it can be very serious at times.

COCCIDAE.

Ferrisia virgatus, Ckll.

Hemichionaspis minor, Mask.

Phenacoccus iceryoides, Green.

Pulvinaria jacksoni, Newst.

Saissetia nigra, Nietn.

The Coccids are also to be found on leaves when the infestation is great. Such infestation is very local, being restricted to one or a few adjacent plants in a field.

3. Insects attacking Leaves.

TETTIGONIIDAE.

Phaneroptera nana, Charp.

Poecilogramma striatifemur, Karsch.

ACRIDIDAE.

**Zonocer~~o~~us elegans*, Thnbg. This grasshopper is an omnivorous pest, likely to appear in numbers near hilly country.

HODOTERMITIDAE.

**Hodotermes mossambicus*, Hagen. The harvesting termite, a large dark-coloured species which issues from the ground to collect leaves. Cotton has been attacked only in the west.

THRIPIDAE.

Retithrips aegyptiacus, Hood. A red thrips not commonly found in numbers, but generally distributed.

CAPSIDAE.

Camptobrochis sp.

Callicratides rama, Kirby.

**Lygus* spp. Potentially a major pest in suitable seasons in the vicinity of Lake Victoria. Causes crumpling of the foliage, shortening of branches and shedding of buds.

**Helopeltis bergrothi*, Reut. Mosquito bug, generally distributed, but only a pest at rare intervals. Causes lesions on stems and leaves, resulting in bunching and dwarfing of the plant if attack is heavy.

JASSIDAE.

***Empoasca facialis*, Jac.

E. benedettoi, Paoli. These Jassids are generally distributed but more injurious in the western zone.

ALEURODIDAE.

Bemisia sp. Whitefly.

APHIDIDAE.

**Aphis gossypii*, Glov. A pest of young cotton.

GRACILARIIDAE.

Acrocercops bifasciata, Wals. Leaf-miner ; never a serious pest.

PYRALIDAE.

**Sylepta derogata*, F. Leaf-roller ; never a serious pest.

LIMACODIDAE.

Parasa vivida, Wlk. Stinging caterpillar.

ARCTIIDAE.

Estigmene unipunctata, Hmpsn. Caterpillar of an ermine moth.

NOCTUIDAE.

Cosmophila flava, F. Cotton semi-looper.
***Prodenia litura* F. Cotton-worm, cutworm.
Xanthodes graellsi, Feisth.
Notolophus vetusta, Hmpsn.

LASIOCAMPIDAE.

Taragama carinata, Wllgn.

LYMANTRIIDAE.

Arctornis producta, Wlk.
A. rubricosta, Fawcett.

SPHINGIDAE.

**Hippotion celerio*, L.

NYMPHALIDAE.

Acraea insignis, Dist.

PIERIDAE.

Catopsilia florella, F.

HESPERIIDAE.

Rhopalocampta forestan, Cr.

These leaf-eating caterpillars are not usually of particular significance, but do appear at intervals in considerable numbers, though such outbreaks are local.

COCCINELLIDAE.

Epilachna matronula, Wse.
E. polymorpha, Gerst.
E. rufosignata, Reiche.
E. similis, Thnbg.

CHRYSOMELIDAE.

Mesoplatys ochroptera, Stål.

LAMIIDAE.

Tragocephala variegata, Bert.

CLYTRIDAE.

Nosognatha ruficollis, Ol.

EUMOLPIDAE.

Syagrus morio, Har. A common leaf-beetle.
S. puncticollis, Lefev.
S. rugifrons, Baly.

GALERUCIDAE.

Ootheca mutabilis, Sahlb.

HALTICIDAE.

Nisotra weisei, Jac. Flea-beetle, occasionally numerous, perforates the leaves.

CURCULIONIDAE.

Dicasticus gerstaeckeri, Fst.
Epipedosoma laticollis, Kolbe.
Gyponychus cervinus, Gerst.
Systates habenatus, Mshl.
S. pollinosus, Gerst.
Tanymecus arushanus, Mshl.

These leaf-eating beetles are generally present, but rarely cause serious injury, though rendering the plant unsightly.

4. Insects Injurious to Flowers.

MELOIDAE.

Actenodes unimaculatus, Pic.
Coryna apicornis, Guér.
Mylabris amplectens, Gerst.

M. bizonata, Gerst.
M. dicincta, Bert.
M. kersteni, Gerst.

RUTELIDAE.

Popillia bipunctata, F.
P. hilaris, Kraatz.
Synistovalgus bifasciatus, Kraatz.

CETONIIDAE.

Diplognatha silicea, Macl.
Pachnoda sinuata, Goldf.

The blossom beetles are generally distributed, but have not been noted to cause serious loss of flowers.

5. Insects Injurious to Green Bolls.

PENTATOMIDAE.

Aeschrus inaequalis, Spin.
Agonoscelis versicolor, F.
Antilochus nigrocruciatus, St.
Atelocera stictica, Westw.
Bagrada hilaris, Burm.
***Callidea bohemani*, St.
Dalsira costalis, Gerst.
Halyomorpha viridescens, Wlk.
Hotea subfasciata, Westw.
Macroraphis spurcata, Wlk.
Nezara chloris, Westw.
N. chlorocephala, Westw.
N. millieri, M. & R.
**N. viridula*, L.
N. viridula var. *torquata*, F.
Sphaerocoris annulus var. *ocellata*, Klug.
Steganocerus multipunctatus, Thnbg.

COREIDAE.

Cletus ochraceus, Sch.
Leptoglossus membranaceus, F.
Mirperus jaculus, Thnbg.
Serinetha hexopthalma, Thnbg.

LYGAEIDAE.

Aphanus apicalis, Dall.
Aspilocoryphus fasciativentris, St.

Graptostethus servus, F.
Lygaeus furcatus, F.
L. pandurus, Scop.

PYRRHOCORIDAE.

***Dysdercus cardinalis*, Gerst.
***D. fasciatus*, Sign.
D. intermedius, Dist.
**D. nigrofasciatus*, St.
D. pretiosus, Dist.
**D. superstitiosus*, F.
Odontopus confusus, Dist.

Of these sucking bugs the following are of importance by reason of their numbers and their ability to transmit internal boll disease—*Callidea, Nezara, Dysdercus*.

GELECHIIDAE.

***Platyedra gossypiella*, Saund. Pink bollworm; restricted to the eastern zone where it is a major pest.

Platyedra cunctatrix, Meyr. A bollworm, pink in colour resembling true Pink bollworm, but easily distinguished in the moth stage. Found on green bolls only in Kigoma district near Lake Tanganyika.

NOCTUIDAE.

**Heliothis obsoleta*, F. American bollworm; an occasionally serious pest in the early part of the season.

Diparopsis castanea, Hmpsn. Sudan or Red bollworm. Only found in experimental cotton growing areas in the extreme south, where the crop was in consequence abandoned.

***Earias insulana*, Boisd. Spiny bollworm.

***E. citrina*, Saalm. Spiny bollworm.

The relative importance of these two species requires investigation. They are general early in the season, but more liable to cause serious injury in the west than in the east. They also attack flower-buds and tips of branches.

6. Insects Found in Open Bolls.

LYGAEIDAE.

Oxycarenus hyalinipennis, Costa. Lesser stainer, or cotton-seed bug; doubtfully of any economic importance.

COSMOPTERYGIDAE.

Pyroderces coriacella, Snell. Pink scavenger worm.

TINEIDAE.

Gnathosaristis coniographa, Meyr. White caterpillar, known only from Ki goma

LYONETIIDAE.

Plemyristis oenochares, Wals. White caterpillar, known only from Kigoma.

COLLECTIONS RECEIVED.

The following collections were received by the Imperial Institute of Entomology between 1st April and 30th June, 1936 :—

Mr. A. M. Adamson :—297 Diptera, 24 Coleoptera, 9 Parasitic Hymenoptera, 38 other Hymenoptera, 9 Lepidoptera, and 50 Rhynchota ; from Trinidad.

Agricultural Officer, Quetta :—8 Lepidoptera and 8 pupa-cases ; from Baluchistan.

Agricultural Research Service, Khartoum :—3 Parasitic Hymenoptera, 11 Lepidoptera, and 3 species of Coccidae ; from the Sudan.

Mr. E. Ballard, Government Entomologist :—2 Dipterous larvae ; from Palestine.

Mr. F. Bernard :—25 Parasitic Hymenoptera ; from France.

Dr. C. E. Bevan :—62 Culicidae ; from Abyssinia.

Dr. F. S. Bodenheimer :—16 Agromyzidae, 15 Parasitic Hymenoptera, and 4 Formicidae ; from Palestine.

Prof. W. H. Brittain :—165 Coleoptera, 15 Lepidoptera, 10 Flatid larvae, 6 other Rhynchota, and 3 Orthoptera ; from Canada and British Guiana.

Mr. G. H. Corbett, Government Entomologist :—26 Diptera, 94 Coleoptera, 70 Parasitic Hymenoptera and 3 cocoons, 12 other Hymenoptera, 39 Lepidoptera, 60 Isoptera, 5 Rhynchota, and 2 Orthoptera ; from Malaya.

Coryndon Memorial Museum, Nairobi :—1,407 Coleoptera and 263 Orthoptera ; from East Africa.

Mr. G. S. Cotterell, Government Entomologist :—3 Diptera, 3 Coleoptera, 8 Parasitic Hymenoptera, 18 Lepidoptera, 25 Isoptera, 4 species of Coccidae, 5 other Rhynchota, and 2 Orthoptera ; from the Gold Coast.

Mr. A. Cuthbertson, Entomologist :—36 Diptera, 8 Curculionidae, and 1,200 Isoptera ; from Southern Rhodesia.

Dr. A. da Costa Lima :—8 Coleoptera ; from Brazil.

Mr. R. C. M. Darling :—16 Diptera, 391 Coleoptera, 9 Rhynchota, and 168 Orthoptera ; from Arabia.

Miss Z. Dickson :—5 Coleoptera and 63 Orthoptera ; from Arabia.

Director of Agriculture, Sandakan :—100 Orthoptera ; from North Borneo.

Director of Public Works, Lagos :—560 Isoptera ; from Nigeria.

Director of Veterinary Services, Kampala :—4 *Glossina* ; from Uganda.

Mr. H. L. Dolton :—55 Parasitic Hymenoptera and 15 cocoons ; from England.

Mrs. K. Dyer :—20 Coleoptera ; from England.

Mr. W. H. Edwards, Government Entomologist :—16 Coleoptera, 2 Lepidoptera, and 1 species of Coccidae ; from Jamaica.

Mr. J. L. Froggatt, Government Entomologist :—10 Diptera, 71 Coleoptera, 20 Parasitic Hymenoptera, 10 other Hymenoptera, 103 Lepidoptera, 5 species of Coccidae, 20 other Rhynchota, 7 Orthoptera, and 4 Ticks ; from New Guinea.

Mr. W. W. Frogbatt :—2 Chalcidae, 7 Tenthredinidae, and 15 Thysanoptera ; from New South Wales.

Dr. L. Fulmek :—14 Parasitic Hymenoptera ; from Austria.

Mr. J. C. M. Gardner, Systematic Entomologist :—7 Curculionidae ; from the United Provinces, India.

Mr. J. Ghesquière :—156 Curculionidae ; from the Belgian Congo.

Mr. F. D. Golding, Government Entomologist :—13 Coleoptera, 12 Lepidoptera, 200 Isoptera, 9 Rhynchota, and 12 Orthoptera ; from Nigeria.

Government Entomologist, Coimbatore :—10 Diptera, 58 Coleoptera, 40 Lepidoptera, 40 Rhynchota, and 4 Orthoptera ; from South India.

Government Entomologist, Lyallpur :—400 Coleoptera, 6 Thysanoptera, 4 Rhynchota, and 200 Mites ; from the Punjab, India.

Prof. A. C. Hardy :—20 Coleoptera ; from England.

Mr. E. Hargreaves, Government Entomologist :—55 Diptera and 2 pupa-cases, 102 Coleoptera, 116 Parasitic Hymenoptera, 121 Lepidoptera, 7 Rhynchota, 16 Orthoptera, 2 Planipennia, and 2 Mallophaga ; from Sierra Leone.

Mr. S. C. Harland :—4 Diptera and 4 pupa-cases, 14 Parasitic Hymenoptera, and 14 Rhynchota ; from Brazil.

Mr. G. F. Hill :—150 Isoptera ; from the Solomon Islands.

Mr. G. V. Hudson :—131 Coleoptera ; from New Zealand.

Imperial Chemical Industries, Ltd. :—4 Coleoptera and 7 Hymenoptera ; from England.

Imperial Entomologist, Pusa :—4 Diptera, 74 Coleoptera, 19 Parasitic Hymenoptera, 150 Thysanoptera, 20 species of Aphidae, 1 species of Aleurodidae, 4 Psyllidae, and 2 other Rhynchota ; from India.

Mr. E. Johanson :—500 Parasitic Hymenoptera ; from Sweden.

Mr. C. J. Joubert :—39 Parasitic Hymenoptera ; from South Africa.

Mr. A. Lazaroff :—10 Coleoptera ; from Bulgaria.

Mr. R. A. Lever, Government Entomologist :—2 Siphonaptera, 30 Culicidae, 2 *Tabanus*, 126 other Diptera, 169 Coleoptera, 6 Hymenoptera, 13 Lepidoptera, 1 species of Aphidae, 60 other Rhynchota, 4 Orthoptera, and 2 Thysanura ; from the Solomon Islands.

Mr. C. J. Louwerens :—106 Coleoptera ; from the Dutch East Indies.

Dr. J. W. Scott Macfie :—10 Siphonaptera, 23 Culicidae, 2 Tabanidae, 462 other Diptera, 2 Coleoptera, 14 Parasitic Hymenoptera, 2 other Hymenoptera, 14 Rhynchota, 4 Psocidae, 2 Collembola, and 2 Mallophaga ; from Abyssinia.

Dr. L. Masi :—25 Parasitic Hymenoptera ; from Italy.

Prof. F. J. Meggitt :—7 Diptera, 245 Coleoptera and 2 larvae, 5 Parasitic Hymenoptera, 49 other Hymenoptera, 1,711 Lepidoptera and 3 early stages, 1 species of Coccidae, 55 other Rhynchota, 51 Orthoptera, 4 Dermaptera, 13 Odonata, 3 Ticks, and 3 Spiders ; from Burma.

Mr. A. R. Melville :—29 Coccinellidae, 16 species of Coccidae, and 2 Chrysopidae ; from Trinidad.

Mr. C. Menozzi :—40 Parasitic Hymenoptera and 13 cocoons ; from Italy.

Mr. J. M. Mimeur :—2 Parasitic Hymenoptera ; from Morocco.

Mr. M. C. Mossop, Entomologist :—30 Rhynchota ; from Southern Rhodesia.

Mr. W. Nageli :—51 Parasitic Hymenoptera ; from Switzerland.

Mr. C. Nicholson :—40 Parasitic Hymenoptera and 150 cocoons ; from England.

Mr. F. B. Notley, Entomologist :—1 species of Coccidae ; from Kenya Colony.

Mr. E. F. PECK, Veterinary and Agricultural Officer :—5 Coleoptera, 300 Formicidae, 2 Lepidoptera and 2 pupae, 12 Isoptera, and 357 Orthoptera ; from British Somaliland.

Mr. Y. R. RAO :—3 Curculionidae and 17 Rhynchota ; from Karachi, India.

Dr. G. RUSSO :—9 Parasitic Hymenoptera ; from Italy.

Dr. H. SCHOUTEDEN :—9 Parasitic Hymenoptera ; from the Belgian Congo.

SELANGOR MUSEUM :—218 Coleoptera ; from Malaya.

Mr. NIHAT SHEVKET :—40 Parasitic Hymenoptera ; from Asiatic Turkey.

Mr. C. SMEE, Government Entomologist :—40 Diptera, 150 Parasitic Hymenoptera, and 4 tubes of Coccidae ; from Nyasaland.

Mr. E. L. TAYLOR :—3 slides of Mites ; from England.

Mr. KEE BING TSEE :—34 Coleoptera, 9 Parasitic Hymenoptera, 19 Lepidoptera, 32 Rhynchota, and 20 Orthoptera ; from China.

Mr. R. VEITCH, Chief Entomologist :—61 Coleoptera ; from Queensland.

Mr. F. G. S. WHITFIELD :—82 Culicidae, 184 other Diptera, 3 Coleoptera, and 9 Lepidoptera ; from the Sudan.

Mr. F. X. WILLIAMS :—23 Diptera and 2 Hymenoptera ; from Hawaii.

Mr. F. WILSON :—11 Parasitic Hymenoptera and 2 Lepidoptera ; from France.

GLOSSINA SWYNNERTONI, AUSTEN, IN RELATION TO VARIOUS VEGETATION TYPES.

By N. H. Vicars-Harris, B.A.,

Department of Tsetse Research, Tanganyika Territory.

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1. Introduction.

The writer took over the Shinyanga fly-rounds in November 1934 from Mr. W. H. Potts, Senior Entomologist, under whose charge they had been since June 1932. The Maswa fly-rounds were not taken over until April 1935, when some of them had been in progress for a few months.

The Shinyanga area, its climate, topography, game and vegetation, have been described by Mr. H. M. Lloyd (1935), by Mr. C. F. M. Swynnerton (1923 and 1936), and by Mr. W. H. Potts in an hitherto unpublished paper, and no further general account is necessary. Table I gives in summarised form a synopsis of the seasons. The Maswa fly-belt lies to the east of the Shinyanga belt, separated from it by the Sukuma Cultivation Steppe, and was, until recently, part of the main *G. swynnertoni* belt that stretches from the bottom of the Serengeti Plains to Arusha and Moshi. As the result of reclamation measures carried out by the Tsetse Research Department during recent years, this belt has been severed from the main fly-belt, and the south-eastern section of this severed portion has again been cut off from the remainder by clearings. In this small isolated block of some 150 square miles an experiment in the exclusion of grass fires as a control measure against the tsetse was initiated in 1934, and fly-rounds were started in that area in order that a control might be kept on the progress of the experiment. Owing to administrative difficulties the experiment had to be discontinued in mid-1935, but the writer decided to continue the fly-rounds and to increase them by two additional rounds in the hopes of producing information, complementary and supplementary, to that from the Shinyanga rounds. The results of the fly-rounds from these two areas appear to throw light upon the vegetational preferences of *G. swynnertoni* and form the subject of this paper.

The writer wishes to thank especially Mr. W. H. Potts, Senior Entomologist, and Mr. S. Napier-Bax, Senior Field Officer, for much useful criticism and advice during the writing of this paper, and to the former for the use of data collected by him from the Shinyanga fly-rounds between May 1933 and November 1934. He is deeply indebted to Mr. B. D. Burtt, Botanist, for the botanical descriptions in this paper, to Dr. C. H. N. Jackson, Senior Entomologist, for advice in the compiling of the figures necessary for the various graphs, and to Mr. H. Harrison, Field Officer, for information regarding game movements. All the above are members of the Tsetse Research Department of Tanganyika. He feels that he must acknowledge the inspiration and guidance he has received from the writings (1930 and 1933) of Dr. T. A. M. Nash, Medical Entomologist, Nigeria, who worked along similar lines upon *Glossina morsitans*, Westw., while a member of this Department. Finally he expresses his gratitude to his Director, Mr. C. F. M. Swynnerton, without whose encouragement and interest this work would not have been done.

TABLE I.

Synopsis of Seasons at Shinyanga and Maswa.

Season	Approximate months	Notes
First rains	December and January	Frequent rain, much cloud, low temperature, little wind. Bush in full flush, grass short.
Break in rains ...	Usually latter half of January or first half of February—varies from 2 to 4 weeks	Very fierce sun, little cloud, very high temperature, little or no wind. Bush in full flush, grass short or medium.
Second rains ...	End February to mid-May ...	Spells of frequent rain and much cloud, with low temperature, interspersed with short periods of sunny dry weather. Bush in full flush, grass long except on hard-pan, etc.
Early dry season ...	Mid-May to end June	Rapidly diminishing showers till end May ; dry sunny weather, little cloud, moderate wind, cool. Bush losing its leaves by end June, grass turning yellow.
Mid-dry season ...	July, August to mid-September	No rain at all, much cloud during July, then cloudless sunny weather, cool, strong wind. Bush leafless and grass mostly fallen from mid-July.
Late dry season ...	Mid-September, October and November	Some showers or short rainy spell during late September or October ; otherwise excessively dry conditions, very fierce sun, sultry nights, periods of high wind. Following showers hillside and riverine bush mostly comes into leaf, but hard-pan, acacia savannah and mbuga communities are leafless. In November young grass shooting.

2. The Fly-rounds.

Fly-rounds as a method of obtaining a picture of the changes in fly density and the vegetation preferences of the tsetse have long been in use and have been described frequently. The method was initiated by Mr. Potts (1930) in 1927, and was much developed by Dr. Nash (1930) while he was a member of this Department. It was introduced to Shinyanga by Mr. Swynnerton in 1929. The Shinyanga fly-rounds as then laid out were intended primarily to give a picture of the changes in fly density in the various blocks of country to which control measures were being applied. In 1930, the round later on referred to as " 4B Round " was laid out by Dr. Jackson, while in May 1933 two important rounds, " Ndama " and " Mantine," were laid out by Mr. Potts. The writer added to the above two further rounds—" Kimburu " and " Upper Ninghwa "—in April 1935. The above fly-rounds are the only rounds at Shinyanga that are dealt with in this paper. The remainder are mostly connected with control measures that are in an advanced stage, and so the figures from them are of little value in considering the relation of the fly to the natural vegetation types.

The 4B Round taps block 4B, which is our control block at Shinyanga. This block is treated as far as possible so as to be representative of untouched fly bush. The game is protected, natives are excluded, and early (and therefore mild) grass fires are started each year. Actually the mild burning has been overdone, in the writer's opinion, with the result that the bush type referred to later as *Commiphora Fischeri* thickened up considerably to the point of partial exclusion of the fly at the end of the 1934–5 rainy season. A fiercer fire in July 1935 checked this tendency for the time being.

The remaining rounds (*i.e.*, Ndama, Mantine, Kimburu and Upper Ninghwa) are all in what is known as Block 11. This block, some 60 square miles in extent, was, up to 1933, burnt annually by organised late fires, otherwise it was untouched. At the end of 1933 it was decided to make the block the site of an experiment in non-burning of the grass as an extension of the smaller experiment described by Mr. Swynnerton (1934). That is to say that the last fire in this block was August 1933 and since then it has been protected. There is no settlement in the block and the game is protected.

In laying out the rounds the usual system was followed of tapping the more common vegetation types and arranging the sectors to include as far as possible only one type of vegetation in each. In country of the type we have at Shinyanga this is not entirely practicable, with the result that there are in every round many sectors containing more than one type. These, for the purpose of the data the writer has endeavoured to obtain, have been ignored, so that in each round only the sectors containing one vegetation type alone are considered. The rounds are carried out in the usual manner—two pairs of rounds being done each month, with an interval of about 14 days between them and one day between the rounds of each pair, the first of which is usually done forwards (starting at the first sector) and the second backwards. The rounds are generally carried out by two boys, but much observation has confirmed that (at any rate in the case of *G. swynnertoni*) the addition of an extra boy, or even two extra boys, makes no obvious difference to the catch. That is to say, the same number of flies that come to two boys will come to three or four boys also.

The period under survey in the case of the three first mentioned rounds is from May 1933 to March 1936. The Kimburu and Upper Ninghwa rounds were carried out for one year only, April 1935 to March 1936. From May 1933 to October 1934 native fly boys carried out the rounds usually quite unsupervised in the field by a European. This was due to the fact that Mr. Potts, who was in charge, was tied largely to his laboratory work and was unable to accompany the rounds himself. From November 1934 to December 1935 the writer endeavoured to accompany one round in every two or at the worst one in every four, according to calls of his other duties. An examination of the graphs in this paper will show that the figures produced from the rounds carried out by natives unsupervised in the field are apparently quite reliable, since the regularity of the fluctuations in apparent fly density in the different vegetation types at the various seasons over the three years under review could not possibly have been obtained from faked catches, the results only becoming apparent after detailed working up.

The Maswa rounds are six in number, but two of them are through such sparse fly as to be of no value to this investigation. There also, supervision by the writer has only been possible on a limited scale owing to the distance of the area from headquarters, but monthly visits have been made to the area since May 1935 and two or more of the rounds carried out personally each visit. Only four of the rounds are dealt with in this paper, Nos. 3, 4, 5 and 6. Nos. 3 and 4 tap principally the area round a big river. Nos. 5 and 6 tap a range of kopjes and hills which form a feature of the northern part of this block and which the writer has always looked upon as the main focus of the fly of the area.

3. The Vegetation of the Fly-rounds.

In dealing with the vegetation it seems simplest, for the purposes of this investigation, to limit the discussion to the more important general types and treat each of these individually. At Shinyanga in the area covered by the rounds these main types may be considered as follows :—

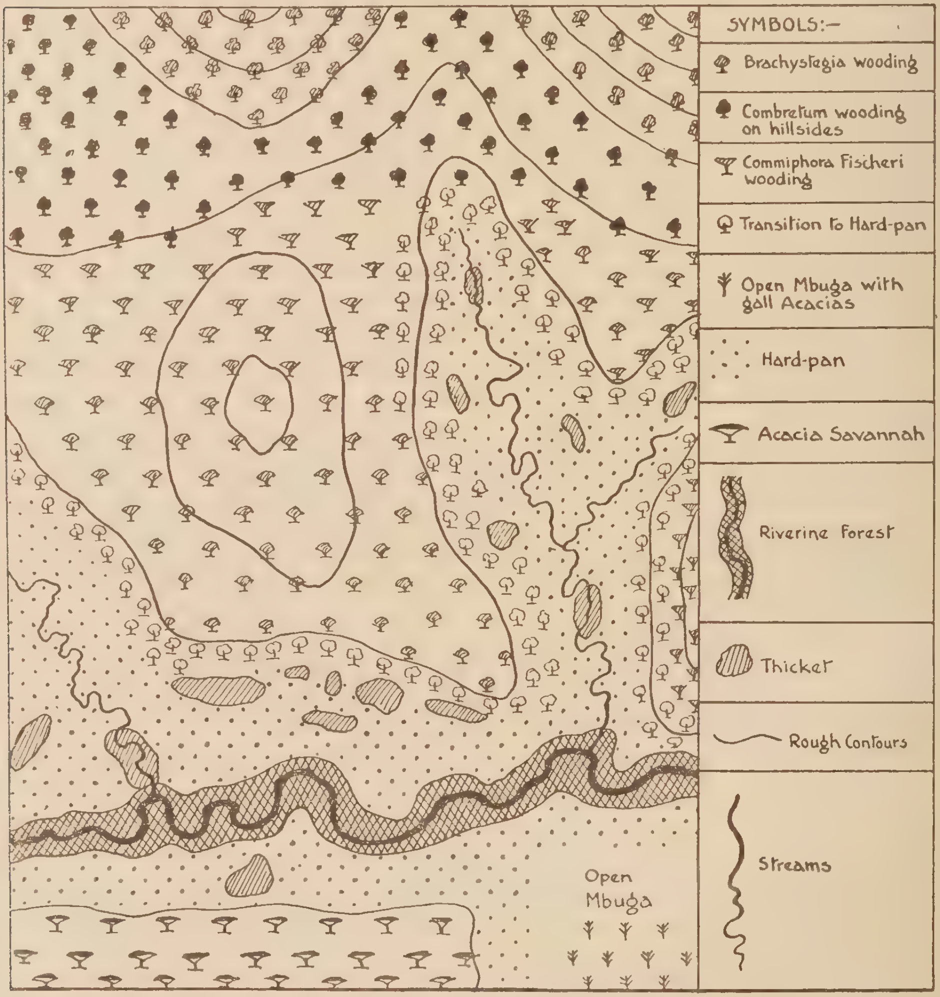
SYMBOLS:—
Brachystegia wooding
Combretum wooding on hillsides
Commiphora Fischeri wooding
Transition to Hard-pan
Open Mbuga with gall Acacias
Hard-pan
Acacia Savannah
Riverine Forest
Thicket
Rough Contours
Streams
Open Mbuga

Fig. 1. Diagrammatic impression of a typical piece of *G. swynnertoni* country at Shinyanga.

1. *Hard-pan.*—Grey soil areas, usually valleys, whose surface soil becomes saturated periodically in the rainy season to a depth of a few inches which overlies a

dry and very hard subsoil almost impervious to water. The principal trees are *Commiphora Schimperi* and *Lannea humilis*, the latter forming small orchard-like groves, with occasional *Acacia senegal*, *A. spirocarpa*, *A. mellifera*, *A. Benthamii*, *A. Fischeri* and *Terminalia Stuhlmannii*. Small scattered thickets occur containing the above and the following thicket species : *Combretum parvifolium*, *Grewia* spp., *Harrisonia abyssinica*, *Maerua trichophylla*, etc. The grass growth is very poor and patchy and consists principally of *Aristida Steudeliana*, *Sporobolus* sp. and *Microchloa indica*.

2. *Acacia Savannah.*—At Shinyanga this is an open type of woodland, generally well grassed, but with small patches of hard-pan occurring here and there. The principal trees are *Acacia spirocarpa*, *A. Benthamii*, *A. rovumae*, *A. Fischeri*, *A. usambarensis*, *Albizzia Harveyi* and, on the hard-pan patches, *A. drepanolobium*, *Commiphora Schimperi*, *Lannea humilis*, etc. A good grass growth chiefly of *Hyparrhenia* spp. and *Panicum maximum* is a usual feature.

3. *Commiphora Fischeri*, etc.—This type, occurring on the better drained semi-eluvial rises, contains as the two most common species *Commiphora Fischeri* and *Combretum Zeyheri*. Other common species are : *Commiphora ugogensis*, *C. pilosa*, *C. Stuhlmanii*, *Ostrioderris Stuhlmannii*, *Combretum splendens*, *Terminalia sericea*, *Boscia Fischeri*, *Pterocarpus Bussei*, etc. Thickets occur containing such shrubs as *Markhamia obtusifolia*, *Markhamia acuminata*, *Strophanthus Eminii*, *Grewia platyclada*, *Abrus Schimperi*, *Acacia pennata*, etc. A luxuriant grass growth principally of *Hyparrhenia* spp., 3½ to 5 ft. in height, is general.

4. *Open Mbuga.*—Areas of open grassland with black cotton soil and patches of hard-pan, sodden during the rains and the soil cracked and waterless during the dry season ; patches of " Ilula " (*Acacia drepanolobium*) occur here and there, while on the areas which are longer waterlogged during the rainy season, we find the yellow-barked gall acacia, *Acacia seyal* var. *fistula*. The grasses are mostly composed of tussocks of *Setaria Holstii* interspersed with *Digitaria regularis* and *Themeda triandra*, and form excellent grazing, and game are commonly seen during the dry season.

5. *Brachystegia Wooding.*—Comparatively small and scattered areas of this type occur on the hillsides in Block 11. This type is mainly composed of *Brachystegia itoliensis* and/or *B. edulis*, with odd *Ostrioderris Stuhlmannii*, *Combretum Zeyheri*, *Commiphora Fischeri*, *C. ugogensis*, *Dalbergia Stuhlmannii*, *Strychnos heterodoxa*, *Pterocarpus Bussei*, etc. scattered throughout. The grass cover is comparatively poor being composed of *Aristida adscencionis*, *Rhynchelytrum roseum* and *Pogonarthria squarrosa* ; these are much interspersed with spectacular annual flowering herbs such as *Bidens lineariloba* and *Pychnostachys leptophylla*.

6. *Combretum Hillsides.*—This type is found on the hillsides, usually surrounding the patches of *Brachystegia* wooding and intermingling with them. It consists principally of *Combretum Zeyheri* and *Ostrioderris Stuhlmannii* with occasional *Commiphora Fischeri*, *Commiphora pilosa*, *Commiphora ugogensis*, *Dalbergia Stuhlmannii*, *Lonchocarpus eriocalyx*, *Terminalia sericea*. The grass is very long, and entirely composed of *Hyparrhenia rufa*, growing from 5 to 6 ft. in height.

7. *Riverine or Heavily Thicketed Hard-pan.*—Rather open hard-pan bordering a strip of riverine forest or dense thicket. The grass is the short feathery *Sporobolus* sp., while the principal trees are *Acacia spirocarpa*, *Commiphora Schimperi*, *C. subsessilifolia*, *Combretum parvifolium*, *Lannea humilis*, *Acacia drepanolobium*, *A. Fischeri* and small scattered thickets, with dense riverine or other thicket immediately contiguous. The difference between this type and type 1 lies in the presence of the belt of dense riverine forest in addition to the small scattered thickets associated with type 1, and to a somewhat different construction of the bush, although the constituents in both cases are similar.

8. *Riverine Thicket.*—Typical alluvial thicket fringing the banks of streams. The chief components are *Acacia pallens*, *A. rovumae*, *A. mellifera*, *Albizzia Harveyi*,

Fagara Merkeri, *Dombeya* sp. nov., *Commiphora Stuhlmannii*, *C. subsessilifolia*, *C. sarandensis*, *Piptadenia Hildebrandtii*, with undergrowth of *Feretia* sp. nov., *Acalypha ornata*, *Anisotes* sp. nov., *Ecbolium trinervium*, etc.

9. *Open Glades in dense Thicket.*—These are glades clothed with 4 to 5 ft. *Hyparrhenia rufa* bounded by dense thickets containing *Dombeya* sp. nov., *Combretum parvifolium*, *Grewia fallax*, *Markhamia acuminata*, *Anisotes* sp. nov., *Commiphora sarandensis*, *Acacia pennata* and *Hymenodictyon parvifolium*, with larger trees of *Albizzia Harveyi*, *Acacia rovumae* and *Commiphora Stuhlmannii* appearing above the general canopy of the thicket.

10. *Transition between Eluvial Vegetation and Hard-pan.*—A feature of the Western Shinyanga vegetation is a strip of open country of variable width separating the normal red-soil *Combretum* woodland of the higher ground from the grey soil hard-pan country in the valleys. On the one hand, the eluvial woodland is clothed with *Hyparrhenia rufa* in pure stands 3½-4 ft. in height, while on the other hand

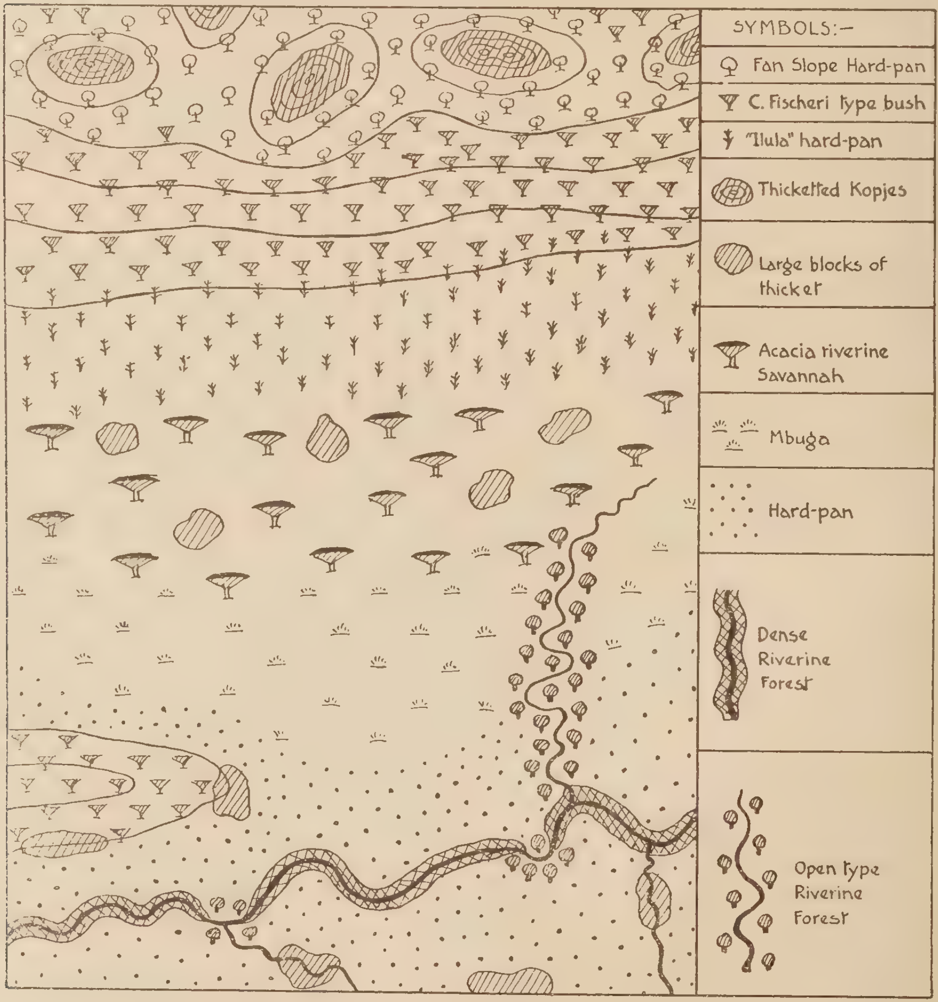
SYMBOLS:—
Fan Slope Hard-pan
C. Fischeri type bush
"Ilula" hard-pan
Thicketted Kopjes
Large blocks of thicket
Acacia riverine Savannah
Mbuga
Hard-pan
Dense Riverine Forest
Open type Riverine Forest

Fig. 2. Diagrammatic impression of a typical piece of *G. swynnertoni* country at Maswa.

we have the hard-pan with short grasses, frequent island thickets and orchards of silvery *Lannea humilis*. Between these two distinct types we find an open strip of gritty sandy soil, often with low granite rock outcrop, clothed with a pure stand of oat-like *Trichopteryx simplex* grass 4 ft. in height, in which scattered shrubs of *Thespesia Garkeana* and *Combretum ternifolium* occur together with the picturesque felty-leaved white-flowered shrub *Ipomoea macrocalyx*.

In the Maswa area types 1, 3, 6 and 7 are well represented, with slight modifications, while in addition there are the following types not yet mentioned.

11. *Acacia rovumae Savannah.*—A grey soil area dominated by tall flat-topped trees of *Acacia rovumae* with small trees of *Commiphora Schimperi* and *Lannea humilis*. Frequent small island thickets are common, composed of *Grewia fallax*, *G. similis*, *Erhetia coerulea* and *Combretum parvifolium*, with frequent succulent climbers of *Cissus quadrangularis* and *C. rotundifolia*. The grasses are mostly *Panicum maximum* under the *Acacia rovumae* trees, with *Cynodon plectrostachyum* in the more open areas. Herbs of *Monechma bracteatum* and *Achyranthes* nr. *aspera* are commonly distributed among the grass, which with the last named herb are readily sought after by game.

12. *A. drepanolobium Hard-pan* (*called Ilula Hard-pan*).—Occupying the bottoms of flat valleys these are composed of grey soil which becomes intermittently saturated with water in the rainy season. *Acacia drepanolobium* (gall acacia) dominates, the trees being 8–12 ft. in height ; groups of *Lannea humilis* and *Commiphora Schimperi* are frequent, especially near the margin, or on occasional termite mounds. The grass canopy is very poor, usually composed of *Aristida adscensionis* and *Steudeliana*, with *Cenchrus ciliare* and *Bothriochloa insculpta*, the last two species appearing locally and more noticeably near the termite mounds, with *Cynodon plectrostachyum*. The soil among the gall-acacia is often almost bare and in quite large areas clothed with a spiny carpet of *Blepharis acanthoides*.

13. *Hard-pan Fan Slopes at the Foot of the Hills or round the base of Kopjes.*—These are grey soil areas which are found locally on the land immediately at the foot of granite kopjes and sloping away from them for one or two hundred yards to the normal reddish eluvial country which constitutes the higher ground in which the kopjes occur. These fan slope areas are of mixed composition, containing large and scattered trees of *Acacia usambarensis*, *Acacia rovumae*, *Lannea Stuhlmannii*, with small trees of *Acacia senegal* and *Commiphora Schimperi*, occurring commonly, and *Acacia stenocarpa* more rarely. Here and there are small groups of gall-acacia (*Acacia drepanolobium*) and island thickets of *Grewia fallax* and *Royena Fischeri*.

The grasses of the fan slopes are richer than in the Ilula hard-pan valleys, being composed of *Cynodon plectrostachyum*, *Cenchrus ciliare* and *Themeda triandra* growing to 1½ ft. in height. These fan slopes change suddenly into the *Combretum* eluvial areas clothed with *Hyparrhenia rufa* in pure stands 3¾–4 ft. in height.

14. *Acacia usambarensis on Hillsides.*—Almost a pure stand of this species on slopes of the hills. Open woodland dominated by well grown trees of *Acacia usambarensis* 40–50 ft. in height. Here and there are scattered flat-crowned trees of *Acacia spirocarpa*. Scattered small trees of *Lannea humilis*, *Commiphora Schimperi*, and *Lonchocarpus eriocalyx* are to be seen generally, while small thickets of *Grewia bicolor*, *G. fallax*, *G. similis* and *Dichrostachys glomerata*, are frequent.

On the lower slopes the grasses are chiefly composed of *Panicum maximum* under the *Acacia usambarensis* trees, with *Cynodon plectrostachyum* in the glades, growing with a profusion of annual herbs such as *Monechma bracteatum* and *Vernonia poskeana*. On the higher slopes the herbage is dominated by a pure stand of *Hyparrhenia rufa* averaging 4 ft. in height.

15. *Open Type Riverine Forest.*—A less-thicketed type of riverine strip with big trees of *Acacia campylacantha*, *Lannea Stuhlmannii*, *Lonchocarpus capassa*, *Kigelia*

aethiopica, *Terminalia Stuhlmannii*, etc. with scattered clumps of dense thicket composed of *Grewia fallax*, *Allophyllus griseo-tomentosus* and *Anisotes* sp. nov.

The grasses grow very tall and are composed of *Panicum maximum* in the shade of the trees and *Hyparrhenia Ruprechtii* in the open, with the reddish *Echinochloa haploclada* in wetter patches ; the grasses are interspersed with clumps of the yellow-flowered composite, *Aspilia* nr. *aspera*, and the tall purple hibiscus, *H. cannabinus*, and *Astrochlaena hyoscyamoides*.

The types represented on each individual round in the two areas are as follows :—

Ndama Round.

Hard-pan (type 1)	2 sectors	824 yards.
Acacia-savannah (type 2)	1 sector	910 ,,
Combretum hillsides (type 6)	2 sectors	1,300 ,,
(Mixed sectors	4 ,,	2,820 ,,).

Mantine Round.

Hard-pan (type 1)	1 sector	350 yards.
Acacia savannah (type 2)	1 ,,	880 ,,
Combretum hillsides (type 6)	3 sectors	916 ,,
Brachystegia wooding (type 5)	2 ,,	1,210 ,,
(Mixed sectors...	8 ,,	6,382 ,,).

Kimburu Round.

Hard-pan (type 1)	4 sectors	2,000 yards.
C. Fischeri, etc. (type 3)	2 ,,	2,130 ,,
Brachystegia wooding (type 5)	1 sector	680 ,,
Transition to hard-pan (type 10)	1 ,,	770 ,,
Open mbuga (type 4)	1 ,,	1,380 ,,
Thicket, glades in, (type 9)	2 sectors	830 ,,
Riverine thicket	1 sector	230 ,,
(Mixed sectors...	5 sectors	3,700 ,,).

Upper Ninghwa Round.

Riverine hard-pan (type 7)	3 sectors	2,440 yards.
C. Fischeri, etc. (type 3)	3 ,,	3,450 ,,
Transition to hard-pan (type 10)	2 ,,	760 ,,
Open mbuga (type 4)	1 sector	870 ,,
(Mixed sectors...	4 sectors	1,620 yards).

4B Round.

Riverine hard-pan (type 7)	2 sectors	1,976 yards.
C. Fischeri, etc. (type 3)	3 ,,	1,909 ,,
(Mixed sectors...	6 ,,	4,396 ,,).

Maswa No. 3 Round.

Hard-pan (not quite typical)	3 sectors	2,040 yards.
Open riverine forest (type 15)	1 sector	870 ,,
Mbuga (type 4)	1 ,,	840 ,,
C. Fischeri, etc. (type 3)	3 sectors	2,280 ,,
Riverine hard-pan (type 7)	2 ,,	1,300 ,,
(Mixed sectors...	2 ,,	1,220 ,,).

Maswa No. 4 Round.

Riverine hard-pan (type 7)	4 sectors	3,290 yards.
Ilula hard-pan (type 12)	2 ,,	1,560 ,,
Mbuga (type 4)	1 sector	1,150 ,,
(Mixed sectors...	7 sectors	3,930 ,,).

Maswa No. 5 *Round.*

Ilula hard-pan (type 12)	4 sectors	1,560 yards.
Fan slopes (type 13)	5 ,,	2,480 ,,
C. Fischeri, etc. (type 3)	9 ,,	4,170 ,,
(Mixed sectors...	6 ,,	3,250 ,,).

Maswa No. 6 *Round.*

Ilula hard-pan (type 12)	5 sectors	3,190 yards.
C. Fischeri, etc. (type 3)	5 ,,	2,290 ,,
Acacia rovumae savannah (type 11) ...	2 ,,	1,340 ,,
Acacia usambarensis (type 14)	1 sector	640 ,,
(Mixed sectors...	1 ,,	380 ,,).

4. The Apparent Relation of G. swynnertoni to the various Vegetation Types.

In considering the fluctuations of fly numbers in the various vegetation communities a very considerable difficulty was encountered at first in selecting transects that were really typical of only one vegetation type. On most of the existing rounds the majority of the sectors were either through rather mixed bush or were spoilt by having a piece of a different bush type added to what might otherwise have been an ideal sector. The new rounds, Kimburu, Upper Ninghwa, Maswa 3 and Maswa 6, were laid out by the writer with this point specially in mind, with the result that the number of mixed sectors has been kept at a minimum on those rounds.

As has already been explained earlier, the mixed sectors are ignored and the round is treated as a disconnected round of pure sectors only. In working up the details of each round the various sectors are classified under their vegetation types and the total length in yards of each type calculated. The monthly mean catches for each type are taken and are reduced to the common denominator of " Flies per 10,000 yards." The resultant figures enable us to graph the monthly fluctuations in apparent fly density for each vegetation type on the various rounds.

While these density curves do show quite clearly the fluctuations of apparent fly numbers in the different vegetation types at different times of the year, the variations in numbers are often so great as to cause very erratic curves on the graphs that make the latter somewhat difficult to follow at times. A method of depicting the relative popularity of each vegetation type was evolved and is as follows—the monthly figures of numbers of flies per 10,000 yards in each of the vegetation types are added together producing the total number of flies per 10,000 yards for the month on the round. Then the number in each type is expressed as a percentage of this total, the result being actually the percentage of apparent fly density in each vegetation type. This appears to give a picture of relative popularity of each vegetation type on any round during the various months. The results both of the apparent density and relative popularity figures are shown in the graphs (figs. 3 to 15) and are discussed herewith.

In reading the graphs it should be borne in mind that the rise or fall that has occurred since the previous month is shown by the line that joins the previous month to the month under survey. That is to say that, supposing the June position is being reviewed, one will look back to the *left* of the June points to see whether there has been a rise or fall during June.

Ndama Round.

In looking at the Apparent Density graph (fig. 3) the first point that strikes the reader is that fly becomes heavily concentrated in the hard-pan during the rainy months, while during the dry season the numbers in the hard-pan decrease to a comparatively low level. That of the *Combretum* hillsides, which has remained very low during the rains, rises sharply to a peak during the latter part of the dry season, when it is actually greater in the *Combretum* than on the hard-pan. Dealing in greater detail, there is a general decrease in density in both types following the last fire (an exceedingly fierce one) in August 1933 and, the writer suggests, numbers do not really recover themselves to normal level till the latter part of 1934. As soon as the 1933–34 rains set in there is a recovery, gradual at first, then very sharp, of the hard-pan density, while that of the *Combretum* remains low. As the rains fade out (it was a year of poor rainfall) the density in the hard-pan decreases, while that of the *Combretum* rises sharply to a peak in September 1934. The showers in October caused leaf flush on the hills and the density in the *Combretum* instantly falls away sharply, so that at the end of the dry season 1934 we have both types at a low level. The rains of 1934–35 were exceptionally heavy, and as they set in the fly numbers in the hard-pan soar away again to a very high point, while those in the *Combretum* remain low. The peak of the hard-pan is reached at the end of the rains, and immediately the dry season sets in and leaf-fall occurs, the hard-pan density falls right away and the *Combretum* rises steeply during the late dry season months to a density higher than that of the hard-pan. Again, at the first showers, the *Combretum* density falls right down, while the hard-pan begins its usual wet season rise.

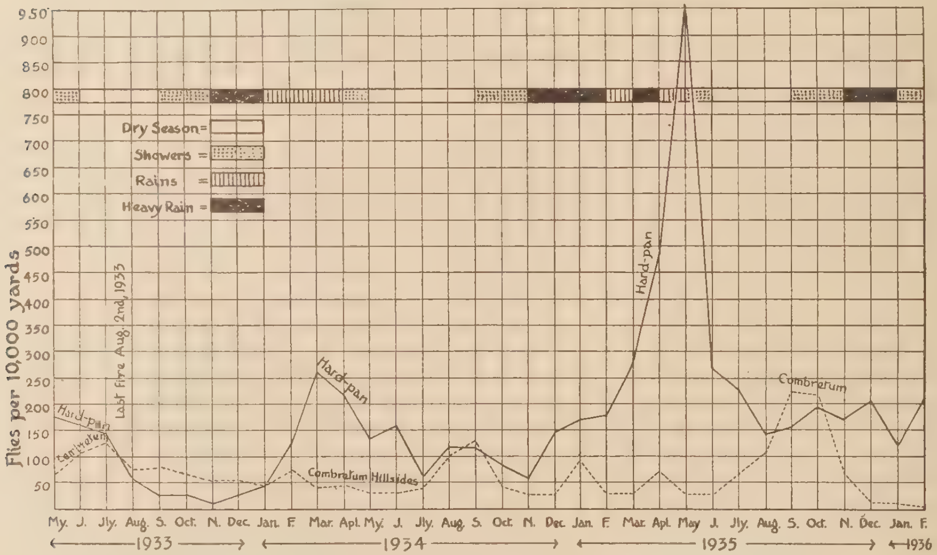

Fig. 3. Graph showing the apparent fly density in the hard-pan compared with that on the *Combretum* hillsides on the Ndama round during three years.

The Relative Popularity graph for this round (fig. 4) shows the fluctuations described above very clearly. The Acacia savannah (which is not shown in fig. 3) remains fairly unpopular right through the year but seems to have its peaks of comparative popularity at the beginning and end of the rains (November and June approximately). It is not in this particular area a popular type, as Mr. Lloyd found in the area he studied elsewhere (Lloyd 1935). On this round, then, it may be summarised that fly becomes concentrated heavily in the hard-pan as the rainy season progresses, and that during the dry season this concentration disappears and fly spreads out into the Acacia savannah first and from there on to the *Combretum* hillsides. When the early showers that herald the new rainy season bring leaf-flush to the *Combretum* community, fly starts to return to the hard-pan type.

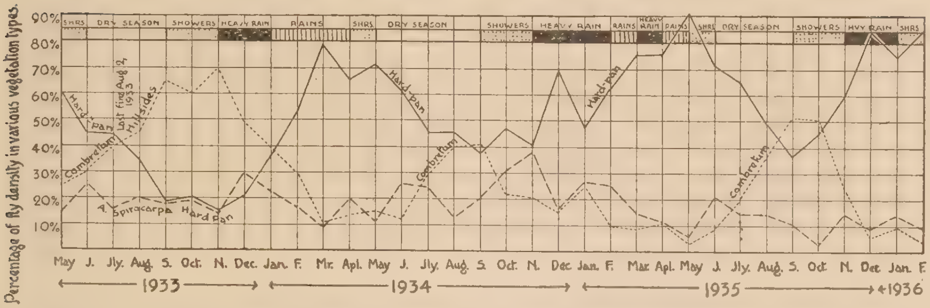

Fig. 4. Graph showing the relative popularity of the three main vegetation types on the Ndama round at various seasons. The " popularity " is expressed by taking the number of flies per 10,000 yards in each vegetation type, adding them together and then expressing the number in each type as a percentage of that total.

Mantine Round.

In considering first the Apparent Density graph (fig. 5) for this round, it is evident that we have something similar to that of the Ndama. A great concentration of fly is at once evident in the hard-pan towards the end of the rains which disappears during the dry season when fly spreads out into the hillside communities (*Combretum* and *Brachystegia*). Treating the graph in more detail, before the last big fire in August 1933 the hard-pan and Acacia savannah curves are falling precipitately, while the *Combretum* and *Brachystegia* are rising as steeply. The fire causes a certain amount of confusion in the graph as, following it, there is a natural falling of numbers in all communities, and during 1934 none of them recovers to 1933 levels except perhaps the hard-pan, which, being short grass country, is usually little affected by grass burning. None the less we have a quite pronounced effect, the hard-pan soaring to a high point in March, the Acacia savannah with a small peak for the short dry season in February then rising in the early dry season, while the two hillside communities fall away to the end of the rains. Despite having been undoubtedly

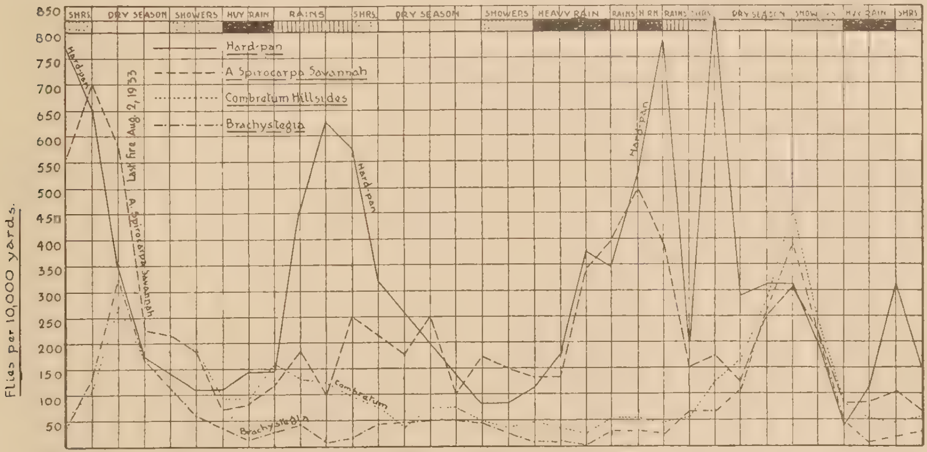

Fig. 5. Graph showing the apparent fly density per 10,000 yards in the four main vegetation types of the Mantine round during three years.

hit much harder than the other two types by the 1933 fire, which was especially fierce in the hills, the two hillside types show a faint attempt at a dry season rise. At the end of the dry season 1934, all types are extremely low (as in 1933 and 1935) and as soon as the rains set in again the hard-pan and Acacia savannah soar away into high figures, the latter with a peak in March and the former in June at the end of the rains. Thence the hard-pan falls to a trough in November at the end of the dry season. The hillside types of vegetation after remaining low right through the rains rise sharply and steadily to a high peak in September, the Acacia savannah also forming a second peak that month. Thence all types fall together to the November trough, and during October and November the fly density is approximately the same in all types. The commencement of the 1935–36 rains sends the hard-pan curve soaring up again, while the other three types come down to a low level.

The Relative Popularity graph for this round (fig. 6) shows the above fluctuations more clearly still; the concentration of the fly into the alluvial communities during the rains, and the break up of this concentration with the spread of the fly into the hillside types during the dry season, are easy to read.

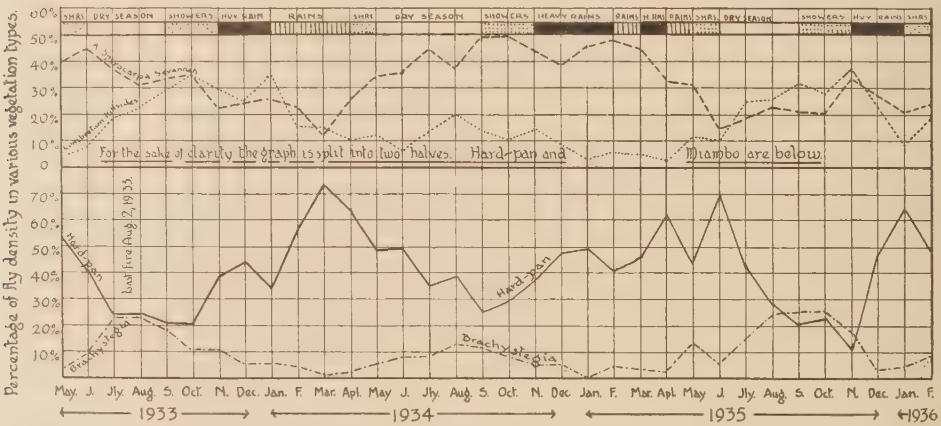

Fig. 6. Graph showing the relative popularity of the four main vegetation types on the Mantine round at various seasons. The "popularity" is expressed by taking the number of flies per 10,000 yards in each vegetation type, adding them together and then expressing the number in each type as a percentage of that total.

In summary, we may conclude that, as on the Ndama Round, the fly is concentrated in the alluvial communities during the rains to the exclusion of the hillside types, while during the dry season this concentration disperses, the hillsides become heavily infested, and fly becomes evenly distributed over all four types.

Kimburu Round.

On this round we only have one year of records, but a much greater range of vegetation types. The picture is somewhat the same however, in that fly is heavily concentrated in the hard-pan and in its transitional zone at the end of the rains and that during the dry season this concentration disperses into the other types. One striking feature of the Apparent Density graph for this round (fig. 7) is the curve for the *Brachystegia* wooding, which shows quite a different state of affairs to this type on the Mantine round. From a low level during the later rains this rises steeply to a peak in June. This particular patch of *Brachystegia* is composed very largely of *B. edulis*, which sheds its leaves at the end of the rains and after an interval of a few weeks only comes into flush again. In 1935 the leafless, or largely leafless, period was observed to be during the latter half of May and all June, and it is just during this period that the fly numbers rise sharply to a peak. A glance at fig. 8 will show the difference and similarity between this and the *Brachystegia* on the Mantine round. This latter is composed of *B. itoliensis* and has only very occasional *B. edulis.* Leaf-fall started in June ; it became leafless in July and remained so until the October showers brought about an immediate flushing of the hillsides. During this leafless period the fly density rose steeply to a peak in September and fell away as steeply as soon as leaf-flush occurred. Thus we have strong indication that it is only during the leafless period that *Brachystegia* wooding is at all popular with *G. swynnertoni.*

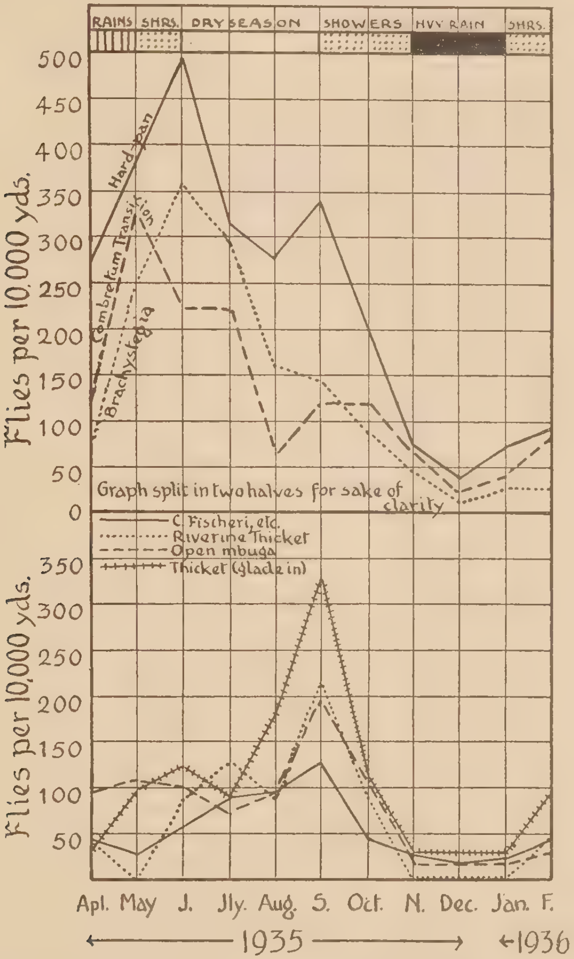

Fig. 7. Graph showing the apparent fly density per 10,000 yards in seven vegetation types of Kimburu round.

Returning to the detailed Kimburu graph, we have seen that the hard-pan, its transitional zone and (in this particular area for reasons explained) the *Brachystegia* wooding, have their peak at the close of the rains and then fall steeply away to the end of the dry season and commencement of the next rains. As opposed to them, the *C. Fischeri* bush, the riverine thicket and the thicket glades, all start at a very low point at the end of the rains and rise to a considerable peak in September at the height of the dry season. The mbuga curve remains more or less steady till August but rises to a sharp peak in September before falling away to low figures, in common with all other types. In common with the other two rounds, already described, we have therefore in this case also a concentration of the fly in the hard-pan and its transition during the rains and a spreading out of the fly into all the other communities as the dry season sets in and progresses, until in September fly is fairly evenly distributed and in October and November sparsely scattered more or less equally over all types. It is interesting to note that the thicketed types and those with the greater amount of shade become more popular as the dry season progresses, which is exactly what would be expected of course from our existing knowledge of this fly, and what the Ndama and Mantine rounds have already shown us.

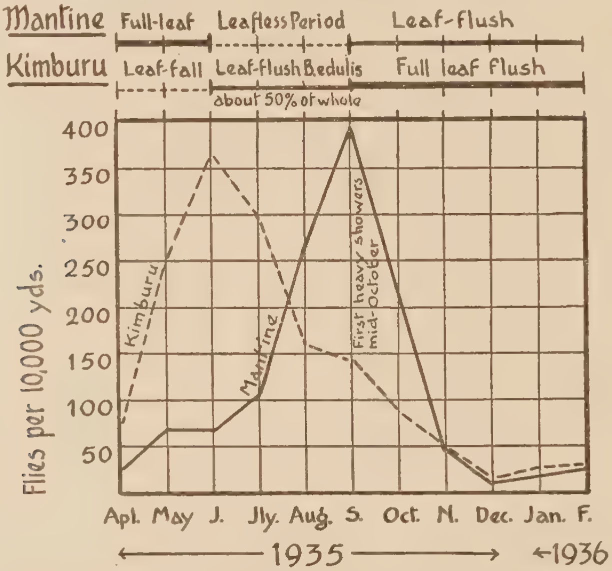

Fig. 8. Graph showing the relations of *Brachystegia* wooding to *G. swynnertoni*. The effects of leaf-fall and leaf-flush on two different fly-rounds.

Upper Ninghwa Round.

We now turn to a round of a different type, a round that taps the environs of a fair-sized riverine strip. Here, as is shown on page 547, we have one new bush type which we have not encountered in the previous rounds, namely riverine hard-pan (type 7 on page 537). A glance at both the Apparent Density and the Relative Popularity graphs (figs. 9 and 10) shows that here we have one vegetation type that appears to satisfy all the needs of the tsetse during the whole year. The majority of the fly of this area remains in the riverine hard-pan, and there is none of the evacuation of this type of hard-pan with spreading out of the fly into other vegetation types that is so characteristic of the other areas we have discussed. In considering the probable reasons for this, it seems fairly clear that this type satisfies a large range of requirements. It has short-grass, extremely open country, which is loved by the fly in the wet season as a habitat and in the dry season as a feeding ground. It is bounded on one side by a dense riverine forest strip, heavily thicketed, along the edges of which the fly apparently breeds and which it probably uses as a rest-haunt. On the other side the ground rises into *C. Fischeri* type bush with a small well-thicketed transition zone. In less well-thicketed hard-pan areas the fly is, the writer suggests, forced out of the hard-pan during the dry season by lack of shade protection into other more shaded types. It does this from necessity, although the other types do not necessarily satisfy its requirements entirely. In this area the riverine hard-pan, satisfying as it does the requirements of the fly through the entire year, remains the source of the whole infestation, and such flies as are caught in other types are probably merely flies searching for food that have followed food out of the hard-pan zone. The hard-pan transition zone curve supports this theory. This transition area is *not* in contact with the riverine hard-pan at all, but is a transition from a less well-thicketed hard-pan strip running right up into the *C. Fischeri* bush. On the Kimburu round we saw that the hard-pan transition curve followed closely the curve of the hard-pan itself with which it is in contact, so we may infer that the curve shown on this graph for hard-pan transition does in fact depict the state of affairs in the hard-pan strip (non-riverine and not well-thicketed) in contact with it. We have, therefore, here the less well-thicketed hard-pan behaving in the same way as on the Ndama, Mantine and Kimburu rounds, while the riverine hard-pan continues to hold the majority of the flies of the area right through the dry season. The

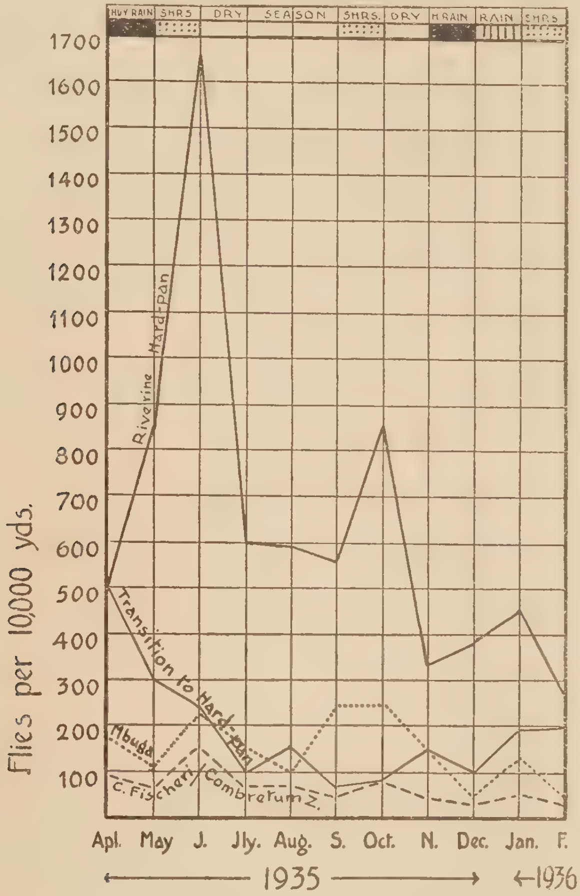

Fig. 9. Graph showing the apparent fly density per 10,000 yards of transect on the Upper Ninghwa round.

April 1935 figure is interesting in this respect, as we have the fly in the two hard-pan types about equal, while, as the dry season sets in, the fly moves down into the riverine hard-pan and evacuates the less well-thicketed type until November when the rains first begin again. The *C. Fischeri* type in this area has already begun to thicken up considerably as the result of non-burning, to which it appears to be the first type to respond. The result may be apparent already in the fly numbers. The mbuga concerned lies alongside the riverine forest strip and probably acts as a feeding ground to that strip and to the riverine hard-pan where the two come into contact.

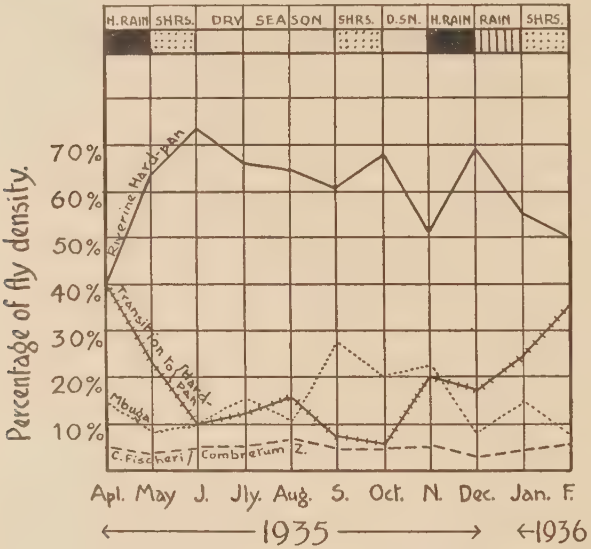

Fig. 10. Graph showing the relative popularity of the four main vegetation types of the Upper Ninhgwa round.

4B Round.

Somewhat similarly to the Upper Ninghwa round we have again here an example of riverine and well-thicketed hard-pan holding the majority of the fly throughout the year. As has already been explained, this particular block is treated as a control block and is burnt annually in a mild way. Looking at fig. 11, it is interesting to note that the fire appears to force the fly out of the *C. Fischeri* bush into the hard-pan, causing a sharp little peak in the hard-pan curve each year. Since this block has been burnt regularly, the *C. Fischeri* bush has kept fairly open, and is therefore much more popular than the same bush type on the Upper Ninghwa round where it has started to thicken up as the result of non-burning. None the less, the hard-pan of this area does hold the greater part of the fly even in the dry season, while during the rains it harbours nearly the whole fly population. Otherwise the curves show the same general fluctuations that the other rounds show, namely a big concentration on the hard-pan during the latter part of the rains, with a tendency for that concentration to disperse during the dry season and for the fly to spread out at that time into the *C. Fischeri* bush.

We have now dealt with five rounds at Shinyanga all showing materially the same picture. In turning to the rounds in the Maswa area it is unnecessary to take them all in great detail. Two of them contain such sparse fly as to be of little interest. The writer deals first therefore with the two rounds he laid out himself specially for this investigation, Nos. 5 and 6. He describes also No. 3, which is of some

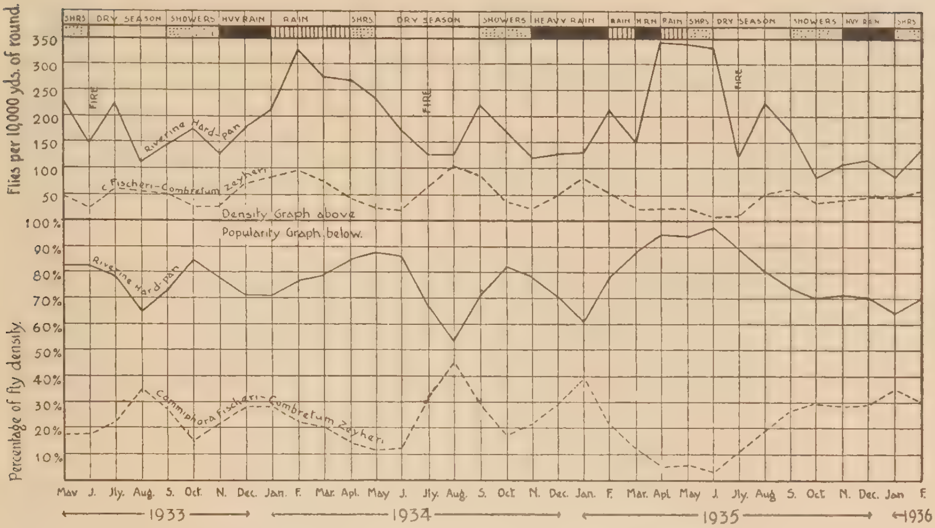

Fig. 11. Graph showing the apparent density and the relative popularity of the hard-pan and the *C. Fischeri-Combretum Zeyheri* bush of block 4B over three years.

interest because it behaves differently in some respects from the other rounds studied, and No. 4 which is a more normal round.

Maswa No. 5.

Figure 12 shows the relative popularity of the three main vegetation types on this round for the nine months since the round was first started. We have two types on this round that we have hitherto not encountered namely, the Fan Slopes of hills and Ilula hard-pan (types 13 and 12 on page 539). The former is found on alluvial deposits on the lower slopes of the kopjes and hills of this area, with a hard-pan type of vegetation. Below them comes the *C. Fischeri* bush and below that again the Ilula hard-pan proper. As will be seen from the graph this fan slope type of hard-pan is very popular in this area right through the year. The hard-pan and the *C. Fischeri* curves both show the usual fluctuations that we have discussed

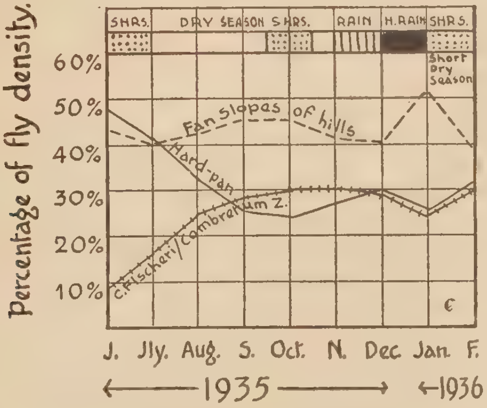

Fig. 12. Graph showing the relative popularity of the three main vegetation types of the Maswa No. 5 round.

so often already in this paper. The fan slopes remain however more or less uniformly popular right through the period. The writer suggests that the reason for this is that in this type the fly has the much favoured hard-pan vegetation in immediate contact with well-thicketed hills and kopjes and with abundant rock breeding-sites. Only towards the end of the rains, when the fly is almost completely excluded from the *C. Fischeri* bush, does the Ilula hard-pan lower down receive its full seasonal concentration. In contrast the fan slopes offer uniformly favourable conditions throughout the year.

Maswa No. 6.

Fig. 13 is rather more complicated in that it shows four vegetation types, two of which we have not yet considered, namely *Acacia rovumae* savannah and *Acacia usambarensis.* The former is a very extensive type in this area and is believed to be of great importance to the fly. It has plenty of fine big trees to give shade; it is quite well thicketed; it has, generally speaking, short grass and is much favoured by game. Mr. C. F. M. Swynnerton in his first visit to this area in 1922 also noted this type as being of particular importance—he refers to *A. rovumae* as "mgongwa" which is its native name (Swynnerton, 1923). The *A. usambarensis* type is not very common, and in this particular case consists of one sector only of pure *A. usambarensis* clothing a portion of the slopes of a hill right down to the edge of the *A. rovumae* country below. Looking at the graph it appears to be of importance to the fly only at the height of the dry season when it is leafless and when the fly tends to draw in towards the hills. The *C. Fischeri* type gives its usual curve, with a sharp little dip showing the effect of the fire. The Ilula hard-pan also shows the curve we should expect, falling steeply during the dry season, with a sharp jump up when the October showers bring about leaf-flush and then "tailing off" until the new rainy season has well set in. The *Acacia rovumae* retained its leaf until the early August fire, and up to this time the curve is rising steadily. During its leafless period the curve falls sharply, but as soon as the October showers bring

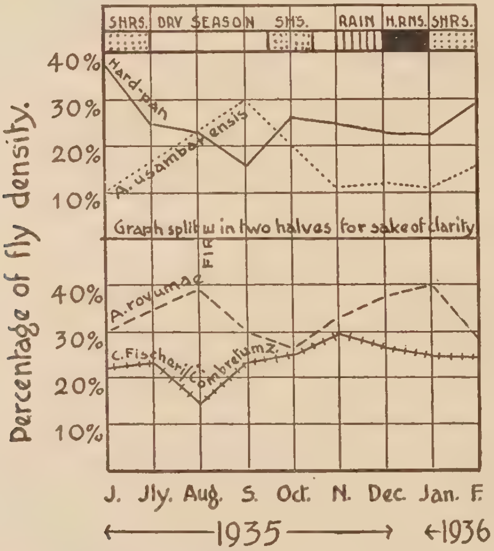

Fig. 13. Graph showing the relative popularity of the four main vegetation types of the Maswa No. 6 round.

on leaf-flush the curve recovers and rises steadily again. Although the broad indications that we are able to obtain from this graph agree with what results elsewhere would lead us to expect, the writer feels that much more information is desirable regarding this type of country, which is not represented at all at Shinyanga.

Maswa No. 3.

The graph for this area (fig. 14) is interesting in that it does not entirely agree with those for the other areas. Notably the *C. Fischeri* type country has its most popular period *during the rains* and is low during the dry season. A type hitherto not dealt with elsewhere, open riverine forest (type 15), shows the curve that would be expected for such a bush type—that is, with the peak of its popularity at the close of the dry season. The hard-pan and mbuga curves are roughly in accordance with what has been seen previously in this paper. The riverine hard-pan is rather indefinite

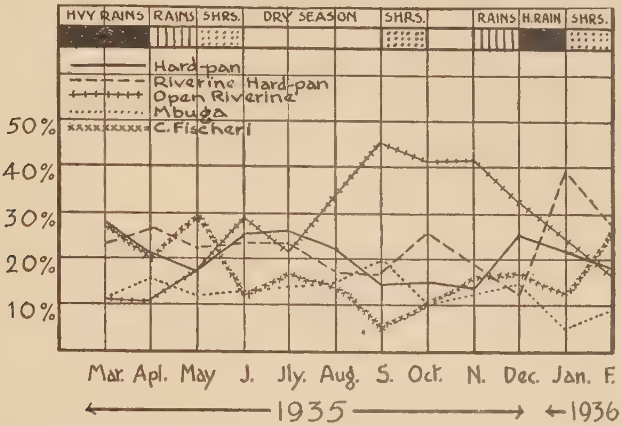

Fig. 14. Graph showing the relative popularity of the five main vegetation types of the Maswa No. 3 round.

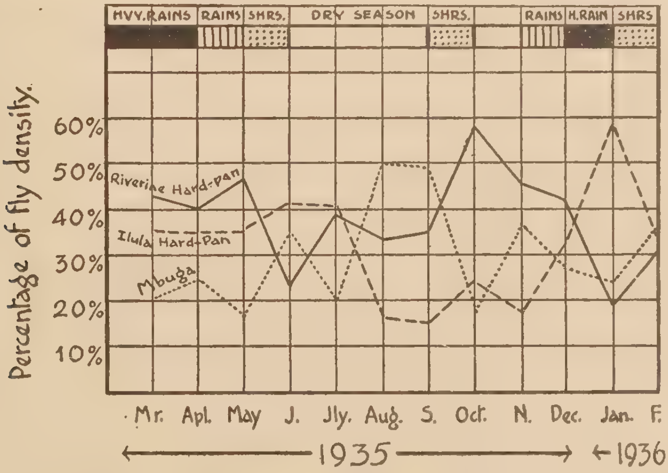

Fig. 15. Graph showing the relative popularity of the three main vegetation types of the Maswa No. 4 round.

and is not nearly so uniformly popular on this round as elsewhere. It is actually not very well-thicketed compared with other riverine hard-pan areas.

Maswa No. 4.

The graph for this round (fig. 15) gives us yet again the same general picture. The riverine hard-pan remains popular throughout the greater part of the year, though owing to its not being *very* well-thicketed it shows a fall during the height of the dry season. The Ilula hard-pan curve agrees exactly with that for rounds 5 and 6, while the mbuga curve is similar to the curves for this type on the Kimburu and Upper Ninghwa rounds.

It has been shown, therefore, that these four Maswa rounds do conform generally to the picture that has been formed from the Shinyanga results. In addition they give some indications as to what to expect from other common types of *G. swynnertoni* bush that are not encountered in the Shinyanga area. The only outstanding instance where they fail to conform to the Shinyanga results is the case of the *C. Fischeri* bush of No. 3 round for which no explanation can be given.

5. Hunger in the various Vegetation Types.

A question that immediately springs to the reader's mind will be " To what extent, if at all, are variations in fly hunger responsible for these variations of fly numbers in the different vegetation types ? " The writer believes that the answer is that hunger is not a ruling factor in most cases and is only to a small extent responsible for these variations. Dr. Jackson, working on the analogy of *G. morsitans*, appeared to show that the hard-pan patches were the combined " homes " and feeding-grounds of this fly (Jackson, 1933). Mr. Lloyd appeared to find that hard-pan, *C. Fischeri* bush and Acacia savannah (the three types that he dealt with), were all capable of sustaining a fly population and acting as a home, provided that the fly could find sufficient food there. He further stated that " Roads and open mbugas provide areas for obtaining food when the tsetse have failed to find food in any or all of the three types of bush mentioned above " (Lloyd, 1935). That is to say, that they were feeding-grounds in the strictest sense.

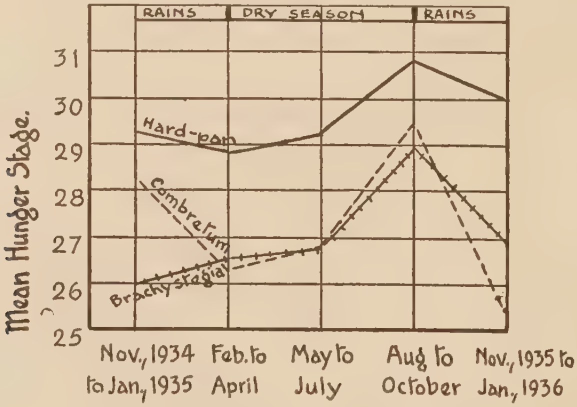

Fig. 16. Fly hunger on the Mantine round.

Of the type of bush studied in this paper the writer believes that only the open mbuga type can be classified as a pure feeding-ground, and the results for that type are probably governed by the hunger factor. In the case of the other types he believes that the meteorological conditions ruling in the various vegetation communities at the different seasons are probably to a greater extent responsible for the fly's apparent vegetational preferences. A brief study of the Mean Hunger Ratio in the different vegetation types during the various seasons does not give much indication that hunger is a factor of prime importance in the matter of fly distribution. Figs. 16, 17 and 18 show the Mean Hunger Ratio in certain of the bush types of the Ndama, Mantine and Upper Ninghwa rounds. Apart from the fact that the less well-shaded vegetation types tend to show a generally higher hunger ratio than the better-shaded country, there is little information to gather from these figures. The perfectly obvious fact that hunger is high at the end of the dry season and lowest at the end of the rains, is clearly shown, but there is no real indication of conflicting curves of hunger ratio in the different vegetation types that could account for the fluctuations of fly density in them. Experiments such as that described by Dr. Jackson as the "Winter Effect Experiment" (1933) tend to show that it is meteorological or some other factors rather than conditions of food supply that control the state of a fly community in any vegetation type.

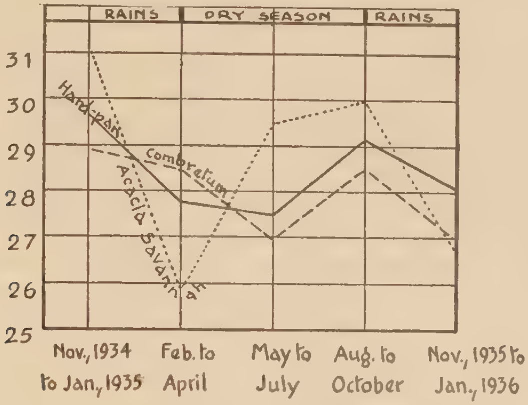

Fig. 17. Fly hunger on the Ndama round.

It is worth while noting the difference between the less well-thicketed hard-pan as compared with riverine hard-pan in this respect. The riverine hard-pan curve (fig. 18) does not go up into a peak of high hunger ratio at the end of the dry season,

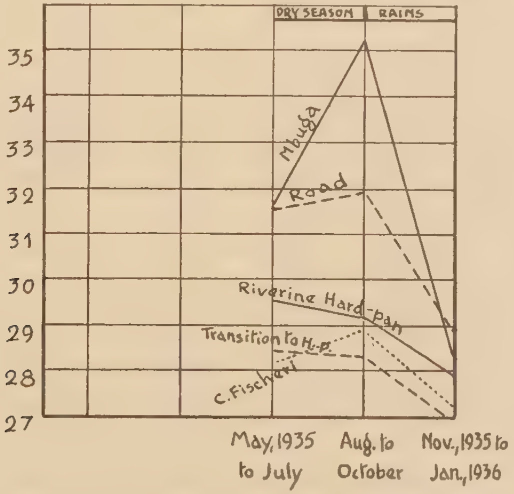

Fig. 18. Fly hunger on the Upper Ninghwa round.

as do the less well thicketed hard-pan areas of the Ndama and Mantine rounds (figs. 16 and 17). Fig. 18 also shows how the two types mentioned already as real feeding-grounds—*i.e.*, open mbugas and roads—show a considerably higher hunger ratio than the actual bush types. Otherwise they seem to follow the same general curve.

6. Conclusions.

There is considerable evidence that *G. swynnertoni* does have very definite vegetation preferences at different seasons of the year. The fly appears to concentrate in the hard-pan type of country during the latter part of the rains, often almost to the exclusion of all other types. During the dry season, however, it spreads out into the better-thicketed and shaded types and becomes often almost evenly distributed right through the bush. Where, however, the hard-pan is in contact with a strip of riverine bush or extensive thickets, this dispersal of the fly during the dry season does not take place to such an extent and a concentration remains in that type of hard-pan country. It must have been to this type of hard-pan that Mr. Lloyd referred when, in the summary of his paper, he stated : " There is no indication that the concentrations of fly in the Hard-pan areas disperse at the end of the rains " (Lloyd, 1935). The hard-pan valleys that he was dealing with mostly had very well-thicketed streams running up them, and probably would have been classified by the writer under Type 7 in this paper. Particular mention must be made of the fact that the results of the present investigation support very strongly the theory put forward by Dr. Nash for this fly in 1932 (Nash, 1933).

It is very evident that more attention should be paid to this line of work, especially in areas such as Maswa, where there are other important types of *G. swynnertoni* bush. The real answer, however, to the whole problem as to *why* the fly appears to have these marked preferences for some vegetation types at certain times of the year and for others at other times lies partly in the laboratory and partly in the problem of the relations of the tsetse and the game. The writer believes that the laboratory investigation that is now in hand under Mr. Potts will throw much light on the subject, while the game experiment that has been in progress at Shinyanga for two years already under Mr. H. Harrison will show to what extent these apparent vegetation preferences of the fly are connected with game movements and preferences.

7. Summary.

(1) A preliminary investigation has been made of the relations of *G. swynnertoni* to the vegetation at Shinyanga and in the Maswa area of Tanganyika Territory.

(2) The investigation has been carried out by means of fly-rounds, the rounds being split up into sectors according to the vegetation types traversed.

(3) The catches of fly are analysed under the different main vegetation types and are reduced to the common denominator of flies per 10,000 yards. Graphs derived from these figures give pictures of the apparent fly density in the different vegetation types at different seasons.

(4) Further graphs showing the relative popularity of the various vegetation types have been compiled by expressing the apparent fly density per month in each type as percentages of the total apparent fly density of the round.

(5) Fifteen different common vegetation types are considered :—

(*a*) Hard-pan. *Lannea humilis-Commiphora Schimperi* and short grass, on hard-pan soil with small scattered thickets.

(*b*) *Acacia spirocarpa* savannah with good grass growth, on grey soil.
(*c*) *Commiphora Fischeri-Combretum Zeyheri* with very good grass, on eluvial ridges.
(*d*) Open mbuga or seasonal swamps on " black cotton " soil.
(*e*) *Brachystegia* wooding growing on the sides of hills at Shinyanga.
(*f*) *Combretum* wooding growing on the hillsides, in contact usually with the *Brachystegia.*
(*g*) Open hard-pan communities alongside a strip of riverine forest.
(*h*) Riverine thicket.
(*i*) Open glades in dense alluvial thicket.
(*j*) Transition between hard-pan and the eluvial ridges above.
(*k*) *Acacia rovumae* savannah in the Maswa area, well thicketed with poor grass growth.
(*l*) *A. drepanolobium* hard-pan with little or no grass in the Maswa area.
(*m*) Hard-pan fan slopes on the hills and kopjes of Maswa.
(*n*) *A. usambarensis* forest growing on slopes of hills in Maswa area.
(*o*) Open riverine forest with little thicket.

(6) The graphs appear to show that fly preferences do exist for different vegetation types at different seasons (see Table II, p. 557).

(7) *G. swynnertoni* appears to become heavily concentrated in the hard-pan during the latter part of the rains, the concentration reaching its height at the close of the rainy season. This concentration then disperses and fly spreads out more and more into the shadier or better-grassed types as the dry season arrives and progresses.

(8) Towards the height of the dry season fly is often more dense on the *Combretum* hillsides and in the *Brachystegia* than in the hard-pan below.

(9) Where the hard-pan is in immediate contact with extensive thickets or a strip of riverine forest this dispersal does not take place, but fly remains in that type of hard-pan, using, it is suggested, the thickets for breeding and resting.

(10) Well thicketed areas become of increasing importance to the fly towards the end of the dry season.

(11) The *Acacia rovumae* forest of the Maswa area appears to be an important vegetation type, as do the fan slopes of the range of hills, the fly appearing to prefer these two types in that area throughout the greater part of the year.

(12) Hunger does *not* appear to be a factor of prime importance influencing the fluctuations of apparent fly density in different vegetation types.

References.

JACKSON, C. H. N. (1933). The causes and implications of hunger in tsetse flies.—Bull. Ent. Res. **24,** p. 443.

LLOYD, H. M. (1935). Notes on the bionomics of *Glossina swynnertoni,* Austen.—Bull. Ent. Res. **26,** p. 439.

NASH, T. A. M. (1930). A contribution to our knowledge of the bionomics of *Glossina morsitans.*—Bull. Ent. Res. **21,** p. 201.

———. (1933). The ecology of *Glossina morsitans,* and two methods for its destruction.—*Ibid.* **24,** p. 107.

POTTS, W. H. (1930). A contribution to the study of numbers of tsetse fly (*Glossina morsitans*, Westw.) by quantitative methods.—S. Afr. J. Sci, XXVII, p. 491.

SWYNNERTON, C. F. M. (1923). Entomological aspects of an outbreak of sleeping sickness near Mwanza, Tanganyika Territory.—Bull. Ent. Res. **13,** p. 317.

———. (1934). Protection of vegetation against grass fires as a possible solution for some tsetse problems.—*Ibid.* **25,** p. 415.

TABLE II.

Hypothetical Table analysing the Graphs of Relative Popularity to G swynnertoni *of the various Vegetation Types at different Seasons.*

Vegetation type as described on p. 536 of this paper		First rains, December to mid-January	Break in rains, Mid-January to mid-February	Second rains, Mid-February to end April	End of rains, May	Early dry season, Late May to end June	Mid-dry season, July, August to mid-September	Late dry season, Mid-September, October and November
Type 1	Hard-pan	Low but starting to rise	Slight fall	Rising very steeply	Very high	Falling	Falling steeply	Very low
2	Acacia savannah	Rising	Rising	High	Falling	Falling	High	Low
3	*Commiphora Fischeri*	Rising	Small peak	Falling steeply	Very low	Rising	High	Falling or low
4	Mbuga	Low	Small rise	Low	Low	Rising	High	Falling or low
5	Brachystegia wooding	Falling	Small rise	Low	Very low	*B. edulis* high *B. itoliensis* rising	*B. edulis* falling *B. itoliensis* high	Falling or low
6	Combretum hillsides	Falling	Small rise	Low	Very low	Rising	High	Falling or low
7	Riverine and heavily thicketed hard-pan	Medium high	Rising	High	Very high	High	Falling but still high	Medium high
8	Riverine thicket	Very low	Very low	Very low	Very low	Rising	Peak	Falling
9	Glades in dense thicket	Very low	Very low	Very low	Very low	Rising	Peak	Falling
10	Transition to hard-pan	Low but rising	Slight fall	Rising	High	Falling	Falling	Very low
11	*Acacia rovumae* savannah	Rising	High	—	High	High	Falling	Rising
12	Ilula hard-pan	Low but rising	Rising	High	Very high	Falling	Falling	Very low
13	Hard-pan fan slopes	Rising	High	High	High	High	High but falling	Medium high
14	*Acacia usambarensis*	Low	Low	—	Low	Rising	High	Falling or low
15	Open type riverine forest	Low	Low	Low	Low	Rising	High	Falling or low

THE BREEDING MEDIA OF SOME COMMON FLIES.

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When studying the biology of the house-fly or any other fly annoying to man and domestic animals with a view to practical control, it is obvious that a correct knowledge of the breeding-places of the species is perhaps the most important problem which the investigator has to solve. As to the common house-fly (*Musca domestica*, L.) it is generally held that this problem has been completely cleared up by several workers years ago, but recent observations in Denmark have convinced the writers that this is not the case. We have arrived at conclusions regarding the chief breeding-places of the house-fly differing from those generally found in text-books.

Our work has not been limited to *Musca domestica*, for we have as far as possible studied the breeding-places of other flies occurring in houses or connected with domestic animals, first and foremost the stable-fly (*Stomoxys calcitrans*, L.). The knowledge of the biology of the stable-fly in Europe is surprisingly meagre, though the practical interest of this species as a tormentor of cattle and horses and a possible vector of infectious diseases is generally recognised.

As our observations may be of some interest to workers in other countries we have collected them in this paper, which constitutes the third of a series containing the main results of our investigations into the fly problem started under the auspices of the Health Organisation of the League of Nations and the Danish Committee of Rural Hygiene and with the support of the Danish Ministry of Agriculture and several private funds.

Previous Work.

Breeding-places of Musca domestica.

It is not our intention to give a review of all the papers dealing with the breeding-places of *Musca domestica* as this has been done previously. Thus the literature prior to 1914 has been excellently reviewed by Hewitt in his well-known book " The House Fly " (1914). We shall confine ourselves to quoting a few prominent investigators in this field, so as to give an impression of the opinions that are at present held almost universally.

Howard was one of the first entomologists who in modern times took up a special and detailed study of the house-fly (from 1895). Already in 1900 he stated that house-flies prefer horse-manure for oviposition, but may breed in human excrement. In his book in 1911 he gave new evidence of the preference of the house-fly for horse-manure but further stated that it may breed in cow-manure, which, however, owing to its rapid drying is not a favourable nidus. Further, it lays eggs in human excreta, pig-manure and other media. Almost the same substances are mentioned in the bulletin of Howard & Bishopp (1924).

Hewitt, who studied the biology of the house-fly between 1905 and 1908, records (1914) the following substances as breeding materials of *Musca domestica* : horse-manure, cow-dung, fowl-dung, and human excrement, both as isolated faeces and in ashes containing or contaminated with excrement. " I found that horse-manure is preferred by the female flies for oviposition to all other substances, and that it is in this material that the great majority of larvae are reared in nature." He summarises the observations made by himself and several other investigators as follows : " All observations which have been made indicate that the chief breeding-place of the house-fly is horse-manure or stable-refuse and that, in addition, it is able to breed in other forms of excrement and in rotting or decaying animal and vegetable substances, especially when they are in a fermenting condition."

Roubaud (1915) judges the value of the different breeding media in the following words : " Le fumier de cheval doit être considéré comme le milieu de développement par excellence de la mouche domestique. Toutes les autres matières auxquelles on accorde habituellement un rôle dans la production de cette mouche (fumiers divers, excréments, purins, ordures) n'interviennent dans ce sens que d'une façon pour ainsi dire nulle. Le fumier de caprins et d'ovins peut également subvenir au développement de la mouche domestique ; mais son importance est purement locale et ne peut être comparée à celle du fumier de cheval. Je n'ai jamais constaté le développement de la mouche domestique dans le fumier de boeuf, celui des porcs, dans les excréments humains ni les ordures."

Austen, too, in his excellent review of the life-history, etc., of the house-fly (3rd ed. 1928), considers accumulations of *fermenting* horse-manure as the chief breeding-places, but mentions further, exposed human faeces, decaying and fermenting organic matter of various kinds, chicken-dung and fresh pig-droppings in pig-sties (" It is stated that in Denmark *pig-sties* are the favourite breeding-places, oviposition taking place on the fresh excreta." As will be seen below this is not quite correct). Further he states that " although the House-Fly does not breed in cow-droppings scattered in fields, cow-dung mixed with straw may form a breeding-material."

In Patton's handbook of medical entomology (part 2, 1931) a wealth of information on the biology and control of flies is to be found. About the breeding-places he writes : " The house-fly, *Musca domestica*, prefers horse manure to any other nidus in which to lay its eggs ; but human faeces . . . is another favourite food . . . ." " It never (or very rarely) lays its eggs in cow dung or in any liquid matter."

These quotations though by no means exhaustive show that leading authorities agree that horse-manure is above all other substances the preferred breeding-medium of the house-fly. Opinions differ, however, as to the importance of other kinds of manure (and other fermenting substances) for house-fly breeding.

Another view was set forth by a prominent Danish agriculturist, Th. Madsen-Mygdal, who in 1915 published some interesting observations on the life-history and control of flies under farm conditions. He maintained that on farms *pig-dung* was the favourite breeding-medium ; during the summer months the bulk of house-fly eggs was laid outdoors in the pig-dung of manure-pits or heaps of manure, while a smaller number was deposited indoors, especially in calf-stalls, but also in foal-boxes and pig-sties. Horse-manure may contain larvae, but generally in small numbers. As to cow-dung he maintains that pure unmixed cow-dung almost never contains larvae if pig-dung is found in the same dump.

The observations of Madsen-Mygdal, published in a Danish agricultural journal, remained unknown abroad, only Austen seems to have had some knowledge of them (see quotation above). Even in Denmark they did not become sufficiently well known as to lead to any great progress in the fight against the flies.

Breeding-places of Stomoxys calcitrans.

As already stated, investigations into the life-history of *Stomoxys calcitrans*, especially with regard to Europe, are rather scarce.

Newstead (1906) was unable to find larvae or pupae of *Stomoxys* in faeces of domestic animals in farm-yards, fields and manure-heaps. But he observed oviposition and larval development in a heap of fermenting grass mowings.

Portschinsky (1910) states that heaps of horse-dung around stables, etc., form the chief breeding-places of *Stomoxys*, which, however, was never observed to breed in cattle-dung in similar situations. *Stomoxys* does not oviposit in horse- or cattle-dung in open fields and woods.

Mitzmain in 1913 published an account of the bionomics of *Stomoxys* in the Philippines. He had observed oviposition in horse-manure and the dung of " carabao " and " bullocks." In the laboratory larval development may take place in other kinds of dung, in bran, flour, etc.

Hindle (1914) writes that *Stomoxys* chiefly breeds in stable manure and heaps of decomposing vegetation.

Wilhelmi (1917) records the oviposition of *Stomoxys* in the dung of domestic animals, preferably cattle-dung. He seems to be of the opinion that oviposition mainly takes place in the byre, but that the eggs or young larvae are brought out with the dung to the manure-heap, where the development is continued.

The most detailed and important information is given by Bishopp (1920 and 1931). " Horse manure has been considered the normal breeding medium for this pest. Investigations made during the outbreak in 1912 showed clearly, however, that the vast majority of the flies bred out in straw stacks, and investigations made around stables and barns indicate that while the fly breeds in pure horse manure, it favours a mixture of this substance with straw . . . ." Further down he mentions " accumulations of fermenting vegetation " as a breeding substance. As to the importance of manure this author states : " The manure piles commonly found near stables where horses are kept furnish suitable breeding conditions. This is especially true in the early spring, when the warmth of the manure appears to be very attractive to the flies for egg laying. Cow-lot manure which has become broken up, especially when mixed with waste feed, is utilized as a breeding place, and so is ensilage, particularly when mixed with straw as is often the case when the bottom of a silo is cleaned out. Experimentally, a few specimens have been reared from pure cow manure, but this substance seems to be unattractive to the adult and not favourable for the breeding of the larvae on account of its very compact texture. The stable fly has never been found breeding in human excrement and does not frequent malodorous places . . . ."

Surcouf (1921) has observed the oviposition of *Stomoxys* in horse-manure even round the feet of the horses and in crevices of the pavement in the stable. When fresh horse-manure is not available the flies oviposit along heaps of manure (" le long des fumiers ") in the soil fouled with debris and urine ; evidently they shun the high temperature due to fermentation.

Patton (II, 1931, p. 224) states that the female " lays the eggs singly in horse-manure, straw soiled with urine, stable bedding, decaying vegetation and household refuse, especially tea leaves."

Séguy (1933) states that the oviposition of the " Stomoxe domestique " takes place on the fresh excrement of domestic animals (horses, cows, rabbits) in stables and byres, more rarely outdoors on heaps of manure, shade, humidity and a certain amount of heat being necessary for development. Sometimes the larvae are found in waste and faeces of rabbit-warrens, poultry-yards, and pig-sties, occasionally in swallows' nests. This applies to the " Stomoxe domestique " which is associated with domestic animals.

Observations on Farms.

When in 1932 the senior author began investigations on the biology of common flies the first question which had to be answered referred to the breeding-places of the house-fly and the stable-fly on Danish farms. Especially the importance of pig-dung as a breeding medium had to be re-investigated, as the only detailed observations made in this country by Madsen-Mygdal were contrary to the experience of investigators in other countries. The author and his then assistant, Mr. Karl Madsen, started by visiting a number of farms where the numbers and occurrence of flies were recorded, and a careful search was made for breeding-places. From our journal a few typical cases may be quoted :

June 1932. *Tune Agricultural School.*—Already our preliminary observations gave a fairly typical aspect of the breeding conditions of the two most important fly species. At the beginning of June 1932 there was a considerable number of house-flies in the pig-sty, whereas in the byre stable-flies were predominant (out of a number of 95 individuals examined there were 2 *M. domestica* and 93 *Stomoxys*). In the horse-stable only a few flies (house-flies) were observed. In the dwelling-house there was a fairly considerable number of house-flies. In the manure-pit of the farm we did not find any larvae at the beginning of the month ; it was rather cold, and evidently the flies had not actually commenced to breed in the open. But in the thick layer of litter and manure in the calf-boxes a rather large number of fly larvae and pupae were found along the walls ; the majority was *Stomoxys*, and some of them *M. domestica*.

At the end of the month many *Musca* larvae were however found in the manure-pit. There was an abundance of larvae in pig-dung some days old, and batches of eggs were observed in dung 1 to 2 days old. But neither eggs nor larvae were found in the cow-dung contained in the same manure-pit. From the last days of June the cows and horses were kept out day and night, and these stables were cleaned. The flies now took to the pig-sty, and at the same time the number of *Stomoxys* decreased perceptibly.

Observations were continued during frequent visits both in that year and in 1933–1935. It still proved that the bulk of the house-flies in summer was produced in the pig-dung of the manure-pit ; a smaller number came from the calf-pens, which in addition produced practically all the *Stomoxys*.

July 1932. *L-gaard.*—A modern and excellently equipped farm belonging to an important company. The inhabitants of the main building were annoyed by flies in the kitchen and rooms. *No pigs* were kept on the farm. In the byre, which was kept very clean, a poisonous spray was used frequently, for which reason there were only few flies in this place. The same was the case in the horse-stable. The manure-pit, situated between the byre and the horse-stables, contained a moderate number of house-fly larvae in the horse-dung, but none in the cow-dung, which constituted by far the greater part of the dung. The cow-dung was covered daily with a layer of peat litter, as the flies were thought to originate from this dung, whereas the horse-manure was left uncovered ! On closer examination we succeeded in demonstrating the places where the flies were produced. In the otherwise clean and orderly calf-stable larvae and pupae of *M. domestica* and *Stomoxys* were fairly abundant in two boxes, which had not been cleaned for some time. But house-fly larvae were found in still larger numbers in a calf-pen which had been arranged temporarily in a barn.

A small neighbouring farm belonging to the same owner was fitted exclusively for pig-keeping. The farm consists of four wings, three of which are pig-sties, the fourth serving as a dwelling-place for two farmhands and their families. The dung is deposited on a cemented place close to the house. In spite of the fact that the stables are modern concrete stables, which are cleaned daily, a vast number of house-flies were found here ; only in a few places have we observed a similar abundance. Of other flies only few individuals were seen (*Stomoxys*, *Lucilia* sp.). In the manure-pit immense numbers of larvae were found.

These first observations were confirmed by investigations made at upwards of 200 farms in the years 1932–35. For the sake of economy of space we shall not give more examples, but the main results of our investigations are as follows :

The House-fly (Musca domestica, L.)

During the summer months (June, July and August), under Danish rural conditions, the house-fly will mainly breed in the open in the manure-pits of the farms. On the majority of Danish farms the stables, except the calf stables, are cleaned daily, and the dung, together with a greater or smaller amount of litter and other refuse, is conveyed to the manure-pit. These pits are almost invariably situated close to the stables and consist of a paved or cemented rectangular area, which is generally uncovered, but enclosed by a low wall ½–1 metre high on three or four sides.* More rarely the dung—daily or at intervals of a few days—is carried away from the farm and placed on a manure heap in the field. On smaller farms the dung of all the domestic animals is placed on the same dump ; on larger farms there may be several dumps.

All our observations show that the favourite breeding-place of the house-flies is the pig-dung placed in the manure-pit, and that the flies will principally oviposit in *fresh* dung which has been carried out on the same or the preceding day. Experiments have, however, shown that if the flies are checked in their access to the fresh pig-dung they are able to oviposit in older dung, at any rate in dung 6 days old, and most likely also in still older dung, as pig-dung will retain its original texture, humidity, peculiar odour, etc., longer than horse-dung, partly at least owing to the fact that fermentation takes place more slowly in this dung than in horse-dung.

On the majority of Danish farms a considerable quantity of pig-dung is daily taken to the manure-pit, so that during the summer house-flies will never lack suitable breeding material. If no special measures are taken (as for instance covering of the pig-dung with other materials) only climatic factors will check the oviposition of the flies in the open. House-flies will hardly oviposit at a temperature below 16 or 17°C. ; further, a continuous strong wind or heavy precipitation may check oviposition. Under such conditions the flies will keep to the houses and deposit their eggs in the stables, but the total amount of eggs will in our opinion be smaller than in a corresponding period of fine and warm weather. Even in fine weather indoor oviposition may take place to some extent, and this should be reckoned with in case of planned control.

In pig-sties the flies will oviposit partly on the straw of the bedding soaked with urine, partly on small remnants of dung in corners and hidden places which are not cleaned frequently, and where the pigs do not trample about. On the other hand, eggs are seldom deposited on the quite fresh excreta which the pigs will mainly discharge in the " cleaning passage." It is likely that these excreta are still too moist for the flies to walk on, and they do not encrust before they are removed during the daily cleaning. The bulk of eggs laid in the pig-sty will be taken to the manure-pit as eggs or young larvae and develop there ; but a considerable part will probably perish during this removal.

Horse-manure deposited on the manure-heap in the open may sometimes contain a considerable number of larvae, whereas in other cases it may be almost devoid of larvae, even if the pig-dung on the same manure heap is teeming with maggots. The temperature of the horse-manure seems to account for this. If the fresh manure is spread in a rather thin layer over a large surface, it will get a suitable temperature of 30° to 40°C. in the upper layer and will be attractive to the egg-laying females. If on the other hand the horse-manure is piled up in a cone-shaped heap, heavy fermentation will take place, and in that case the temperature may, even on the surface, rise to 50° or more, so that no oviposition can be effected, and eggs or larvae that might already be found there will be killed (observations at Faurholm in 1933 and 1934). On the whole, the horse-manure on ordinary Danish farms plays a minor rôle in fly production, because in summer, when the horses are generally out, only a small amount of horse-manure is deposited on the manure-pit.

In horse-stables where the horses are ordinarily placed in stalls, oviposition will only be scanty, as the flies are reluctant to oviposit on the quite fresh excrement, and as the stables are generally cleaned every day. On the other hand, loose-boxes may become important as breeding-places, if the manure and litter are allowed to accumulate there for a longer period. In military stables it was the custom previously in consideration of the animals' legs to let the horses stand on so-called " mattresses " of compact litter and manure ; these " mattresses " offer excellent breeding conditions for flies.

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* See photographs on Plate XII, Thomsen 1934.

The house-fly will not oviposit in single horse droppings scattered in fields and on roads. Evidently they dry up too rapidly and are in addition broken up by birds.

Thorough investigations have shown that under the conditions prevailing in this country the house-fly will only exceptionally oviposit in pure cow-dung. On the numerous farms visited by us we have not, except in two or three cases, found larvae of *Musca domestica* in cow-dung in any number worth mentioning ; however, larvae of other fly species (*Scatophaga stercoraria*, *Sargus cuprarius*, *Syritta pipiens*, *Paregle cinerella* and several species of smaller Diptera) have been found commonly ; these species never or rarely visit houses, and their larvae will never occur in the numbers in which *M. domestica* may appear in pig- and horse-dung. The repugnance of house-flies to cow-dung is of great practical importance, as cow-dung is generally predominant in manure-pits.

It may of course happen that house-fly larvae will wander from the pig- and horse-dung in the manure pit into the cow-dung, but this occurs only to a small extent. Only in a single case, under special circumstances, have we observed oviposition in a considerable degree in cow-dung, viz., on 9.vi.1934 at Faurholm. On and from the 4th June the pig-dung on this farm had been covered with cow-dung in order to try to prevent oviposition, a method that in other places has given excellent results (Thomsen 1934). Two unfortunate circumstances, however, in this case involved a failure of the experiment. In the first place there was an exceedingly large number of flies on the farm at the commencement of the experiment, secondly, for litter in the stables a considerable quantity of chaff had been used, the greater part of which was now lying on the surface of the manure-pit ; the chaff was wet with urine and in fermentation, so that the temperature was fairly high, about 30°C. In this moist, but at the same time porous and warm material—and not in the cow-dung proper—the house-flies laid their eggs ; we found on 9th June three large batches of eggs which hatched in a few days, whereupon the larvae gradually spread over the surface of the manure-pit in the layer of cow-dung.

In cow-houses, where adult house-flies are often present in large quantities, their larvae are seldom found. Quite exceptionally a small number may be found in the remains of humid, fermenting fodder in some or other corner (*cf.* below under *Stomoxys*).

On the other hand, calf-stables play a very important part in the propagation of the house-fly. The young calves are generally left untethered in pens or boxes, which are often situated on a lower level than the stable floor proper. These boxes are not cleaned daily, but sometimes only at intervals of weeks and even of months ; but fresh litter is supplied frequently, which absorbs the urine and affords a dry and soft couch to the calves. The result is that the bottom of the box is covered with a layer, often several feet thick, of compact litter mixed with dung and wet with urine, only the surface being fairly dry. In this bedding larvae of the house-fly (and stable-fly) are often found in abundance. The house-fly larvae concentrate mainly in the calf-dung proper, so that the lumps of excrement may be white with larvae. The pupae are mostly found close to the walls ; we have found them down to a depth of 15 cm.

We have not had occasion to investigate the importance of sheep- and goat-dung as a nidus. But in several places we have found many house-fly larvae in chicken-dung, and a few times in rabbit-dung and in human faeces. On a few occasions larvae have been observed in kitchen refuse and decaying vegetable substances ; but all these places play a minor part only.

From all our observations we can then summarise as follows : On Danish farms the house-fly in summer breeds in the first place in fresh pig-dung deposited in manure-pits or heaps of manure, in the second place in the bedding of the calf-stables, next in horse-boxes and pig-sties ; whereas horse-manure in manure-pits or heaps of manure is of minor importance in this respect.

The Stable-fly (Stomoxys calcitrans, L.)

In Northern Europe *Stomoxys* is mainly an indoor insect, or more precisely a stable insect, it being seldom found in human dwellings. Occasionally *Stomoxys* may find its way to verandas or rooms, but it is not a constant member of the fly fauna of rooms like *M. domestica.*

Stomoxys particularly belongs to cow-houses and calf-stables, where it can be the predominant species ; in smaller numbers it is present in pig-sties and horse-stables, where *M. domestica* is the more frequent species. Both larvae and adult flies can be found throughout the entire winter in cattle stables, propagation being continued in the winter in the stables in which the temperature is suitable (in cow-houses the temperature in the winter is rarely below 15–16°C., and sometimes 18° or even more). In spring the number of adult stable-flies increases up to the moment when the cows and older calves are put out to pasture, for which reason the possibilities of blood-sucking decrease considerably. In summer we find that stable-flies concentrate round calves and bulls, if these are left in the byre ; otherwise they will take to the pig-sties (more rarely horse-stables), but the total number will normally be smaller than in the spring. In the autumn, when the cows are brought home to the stables, the number of stable-flies increases in the cattle-stables, while these flies will gradually disappear from the pig-sty. When winter comes, the number of *Stomoxys* will again decrease in the cattle-stables. In the stables *Stomoxys* will either be present on the animals, whose blood they suck, or they will be in repose on the ceiling or on the upper part of the walls and pillars, presumably attracted by the higher temperature close to the ceiling.*

Stomoxys may sometimes be observed in the open ; thus it is rather frequently seen on the outer walls of stables and now and then it may be observed on pasturing cattle, particularly in the vicinity of homesteads. It is not nearly so frequent on pasturing cattle as *Lyperosia irritans* and *Haematobia stimulans* (*cf.* Thomsen 1934) and it is generally seen in small numbers only (for instance 3–8 per cow). Our notes show that it is mainly observed in the open in two periods, namely, in spring (April), when we have seen it only on walls, etc., and in the autumn (especially in the latter part of September), when it is observed particularly on pasturing cattle. As to the cause of this we cannot say anything definite at present, possibly our observations are not sufficiently comprehensive.

In countries with a warmer climate *Stomoxys* lives to a greater extent in the open (*cf.* for instance Bishopp 1920 and Séguy 1933). We must therefore suppose that originally it belonged to warmer regions, and not until the introduction of domestic animals and the erection of stables for cattle did it get an opportunity of spreading to colder parts of the globe (a similar view is held by Nieschulz 1933). It is possible that the same thing holds good of the house-fly too.

Under the conditions prevailing in this country the stable-fly breeds especially in calf-boxes. There are here at the same time the best possibilities for nourishment and for oviposition, which latter takes place in the bedding of the boxes, consisting of litter and dung which is wet with urine. The eggs are deposited singly, often close to each other, and not in large cohesive batches as in the case of *M. domestica* ; they are forced a little way into the surface of the dung so as to be protected against drying up.

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* Nieschulz (1933, a and b) has shown that the preferred temperature of *Stomoxys* lies about 28°C.

In these places the temperature is generally between 20° and 26°C. and will seldom rise to 30° or more. Generally speaking we have never found *Stomoxys* larvae in strongly fermenting dung with a high temperature, in contrast to *Musca* larvae which most commonly occur at temperatures ruling between 30° and 40°C. In the calf-pens the *Stomoxys* larvae will generally choose the moist straw and not, like *Musca* larvae, the pure dung. As a rule they will wander about singly in the upper layer of the medium. The pupae are often found in large collections along the walls.

Stomoxys breeds also in humid remains of straw, fodder, etc., left in corners and crevices of the stable. It is not necessary for these remains to be mixed with dung, but a certain degree of humidity is a necessary condition for oviposition and larval development. It is particularly in the byre that such breeding-places are found, and especially suitable are the interspaces behind the self-filling water troughs, which are difficult to clean and constantly wet when the cows are drinking and splashing the water.

In horse-manure we have only rarely found *Stomoxys* larvae, although our experiments discussed below show that this fly will readily oviposit in this kind of manure. We shall return to this fact later.

In a few cases we have observed *Stomoxys* larvae in pig-dung mixed with straw dumped in a manure-pit, but we only found a few larvae in each place. Whether in these cases the eggs have been deposited on the dung in the sty or in the open after removal of the dung we cannot say with certainty ; but we are inclined to think that the former is the case. Often *Stomoxys* will be entirely absent in pig-sties, but not rarely some individuals are seen, particularly if the cattle-stalls are vacant in summer ; on 27.vi.1933 (the day of oviposition in experiment II) we noted that there were comparatively many *Stomoxys* in the pig-sty at Faurholm. It should be observed that *Stomoxys* will bite the pigs, particularly on the back of their ears at the base.

In pure cow-dung *Stomoxys* larvae are very seldom met with ; on the contrary, they may sometimes appear in material mixed with cow-dung, but in which straw or other vegetable substances are predominant, so that the texture of the whole material is similar to that of the bedding of the calf-boxes. Evidently oviposition in byres which are cleaned daily takes place to a slight extent only.

Whether *Stomoxys* under the conditions prevailing in this country oviposits in the open or only indoors in the stables we cannot decide with certainty. We have sometimes seen adult *Stomoxys* on the manure heaps, but we have never directly observed oviposition there. In a number of cases we have found *Stomoxys* larvae in the manure-heaps but always under such conditions that they might very well have been deposited there with the dung from the stable as eggs or larvae. There is hardly anything to prevent oviposition from occurring in the open, even under our climatic conditions ; but quantitatively it is of no importance compared with oviposition in stables.

Oviposition Experiments in 1933.

The above-mentioned observations show that house- and stable-flies on Danish farms mainly breed in definite kinds of manure. This may be due to a marked preference of the flies for these particular kinds of manure, *i.e.*, to definite tactic reactions of the adult, but external factors such as the quantity of and access to different kinds of manure may also be of consequence.

In order to ascertain to what extent internal and external factors are involved we have made some experiments during which we gave the flies the option of the four kinds of manure of our most important species of domestic animals for oviposition. The experiments were made in the summer of 1933, three on the State Farm, Faurholm, the fourth at Tune Agricultural School. For each experiment 16 vessels were used, 4 of which were filled with pig-dung, 4 with horse-dung, 4 with calf-dung and 4 with cow-dung. The dung applied was as far as possible taken fresh from the animals, but we did not sterilize it by heating, as we would not risk a change of the qualities of the dung as compared with the natural dung. Of course this procedure does not warrant with absolute certainty that the dung employed might not have contained eggs at the commencement of the experiment—and some results indicate that this may have been the case for a few of the vessels. There is, however, no reason to believe that this circumstance had any appreciable influence on the total result of the experiments.

In experiments I and III we used stone jars of a depth of 26·5 cm., an external diameter of 19 cm. and a surface area of dung of about 283 sq. cm. For experiments II and IV we had to use somewhat larger metal vessels (depth 39·5 cm., inner diameter 25 cm., surface area 491 sq. cm.), as when these experiments began, the previous ones were not yet finished. Vessels Nos. 5, 6 and 13 in experiments II andV were, however, somewhat smaller, having a surface of about 314 sq. cm. It is admitted that this was objectionable from an experimental point of view, but it was due to the dificulty in obtaining quantity of fresh calf-dung to fill four large vessels ; therefore the numbers of flies yielded by the vessels with calf-dung in experiments II and IV cannot be strictly compared with those yielded by the other vessels in the same experiments. The larger vessels used in experiments I and III may have been more attractive to the egg-laying flies than the smaller vessels employed in the two other experiments ; on the other hand there is no clear evidence that this was really the case.

The pig-dung and horse-manure had their normal appearance and were practically uniform during all four experiments. It was more difficult to procure uniform cow and calf-dung for all the experiments ; it should especially be pointed out that what in experiment III is called "cow-dung" is dung of one-year-old bullocks, the cows being kept at a good distance from the farm at that time, so that fresh cow-dung could only be procured with difficulty. The calf-dung originated from 3 to 6 months-old animals, fed with milk.

In all experiments the 16 vessels were arranged in two series, A and B, each comprising 8 vessels (2 with each kind of dung). Series A (Nos. 1 to 8 in the tables) were exposed to oviposition of the flies in the open, the vessels being placed close to each other near the manure-pit of the farm (at that end which contained pig-dung), where many flies (particularly house-flies) were to be found. Series B, the "indoor series," in experiments I and III was placed in the calf-stall, where besides a great number of house-flies there was a considerable quantity of *Stomoxys*, whereas the B-vessels in experiments II and IV were placed in the pig-sty, where the fly population mainly consisted of *Musca domestica*, although *Stomoxys* was present too.

It appears from the tables that various other species of flies also deposited their eggs in some of the vessels, although few or none of them were observed in the vicinity.

After the vessels had been exposed for oviposition for a number of hours* they were taken to the laboratory, where they were covered and stored in a cellar, in which the temperature was 18 to 22°C., the surface temperature of the manure (1·5 cm.) was measured daily until the flies began to hatch. For the collection of the hatched flies we made use of their positive phototaxis, the muslin placed over each vessel being further covered with a layer of black paper, in the middle of which a hole was cut, which was closed with a perforated cork. On this was arranged a cylinder of celluloid, in the upper end of which there was a small circular opening closed with a small cork. The hatched flies were enticed by the light into the cylinder, which was emptied once or several times daily. The small cork at the top was replaced by a cotton plug soaked with ether, so that the etherized flies could easily be shaken out into a specimen tube. All the flies from each single vessel and each day were kept separately in alcohol and were later determined as to species and counted. Of the small species—of which some appeared in enormous quantities—no counts were made.

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* The time of exposure was not the same in the different experiments, the main point being to obtain abundant oviposition in the vessels so as to make the difference between the different kinds of manure as evident as possible.

Mr. Karl Madsen, B.Sc., has attended to the technical performance of the experiments on the farms and has assisted us in collecting the hatched flies, for which assistance our thanks are due to him. We are indebted to S. L. Tuxen, M.Sc., of the Zoological Museum in Copenhagen, for valuable assistance in the determination of some of the species; we also wish to thank Dr. K. L. Henriksen, in charge of the Arthropod Department of this Museum, for kind permission to use the collections of Diptera of the department.

As regards the individual experiments we wish to make the following remarks:

Experiment I.—Faurholm, 8th–9th June 1933. Stone jars. Series A, were exposed to oviposition on 8th June from 9 a.m. to 4 p.m., and on 9th June from 8 to 12 a.m.; in the meantime the jars were covered; the jars stood beside a pig-dump. Series B stood uncovered in a calf-stall from 9 a.m. till 12 a.m. the following day. It was fine weather, the day temperatures ranging from 15° to 22·5°C. No rain fell.

Experiment II.—Faurholm, 27th to 28th June 1933. Metal vessels. Series A was exposed to oviposition near a pig-dump on 27th June from 10 a.m. to 4 p.m. Series B was placed in a pig-sty from 27th June at 11 a.m. till 28th June at 12 a.m. It was cloudy with light showers. The day temperatures ranged from 15 to 20°C., and on each of the two days the precipitation amounted to 4 millimetres.

Experiment III.—Faurholm, 28th to 29th July 1933. Stone jars. Series A was exposed to oviposition beside a pig-dump from 28th July at 10 a.m. till 29th July at 2.30 p.m., but jars nos. 2, 4, 6 and 8 from the open were taken into the pig-sty at 12 a.m. on Friday 29th and left there till 2.30 p.m. Series B was exposed to oviposition for the same length of time inside a calf-stall where there was a great number of *Stomoxys*.

The recorded day temperatures ranged from 15° to 25°C. On the 28th the precipitation was 0, on the 29th 1 millimetre.

Experiment IV.—27th June to 28th August 1933. Metal vessels. Series A was exposed to oviposition at a manure-pit which contained all four kinds of manure, on the 27th from 8 a.m. to 6 p.m., and on the 28th August from 7 a.m. to 6 p.m. Series B remained during the whole period in a pig-sty, which was in the same building as the byre and calf-stall, for which reason both *Musca* and *Stomoxys* were abundant.

The day temperatures ranged from 12° (at 8 a.m.) to 21° (at noon). No rain fell.

Results of Experiments.

The results of the individual experiments are given in Tables II–V, and in the case of *M. domestica* and *S. calcitrans* they have been graphed (figs. 1–4). It proved impossible to decide from the experiments whether the various flies prefered to oviposit in the open or in the stable, for the figures vary in the experiments. Although there can be no doubt that the weather affected the behaviour of the flies, the difference in the time of exposure for A and B in the experiments was certainly of importance also. For an answer to this question we must therefore rely on direct observations and not on the experiments, and we have accordingly united the A and B series in the graphs.

On the other hand, the difference between the power of the individual kinds of manure—expressed in number of hatched individuals—to attract the ovipositing flies is seen clearly from the experiments, particularly as regards *Musca* and *Stomoxys*; it is further obvious that generally speaking the figures show good agreement with

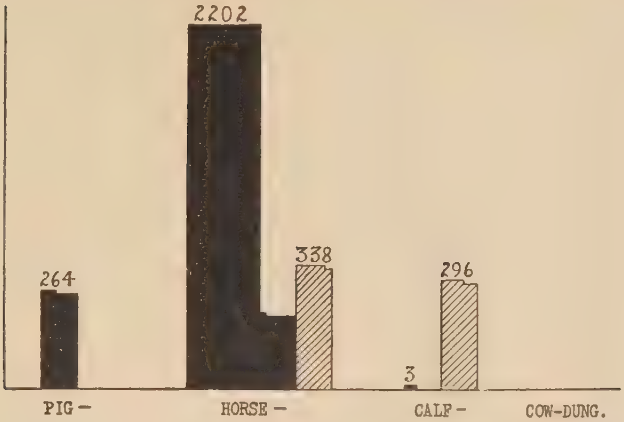

Fig. 1. Experiment No. 1. (See Table II.)

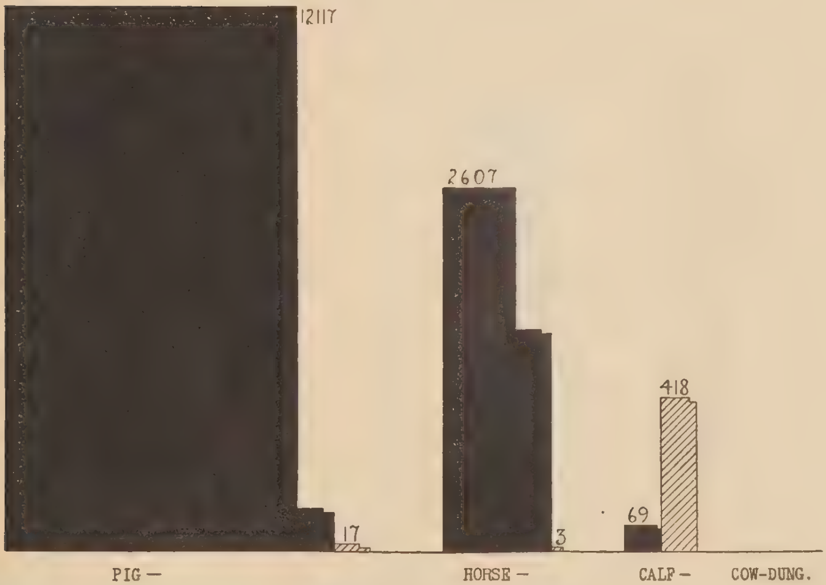

Fig. 2. Experiment No. 2. (See Table III).

the results of direct observation. This seems to prove that the difference in fly-production of the various kinds of manure is primarily attributable to internal (physiological) factors in the flies, *viz.*, a marked preference for particular kinds of manure. No doubt this is a question of chemotropism, the smell of the different kinds of manure attracting the ovipositing flies in very different degrees. We have not studied what specific odours are particularly effective ; investigations made by others tend to show that ammonia is important in this respect, but no doubt other substances are effective also. It may be that also hygrotaxis and thermotaxis contribute to attract the flies to the manure ; further studies on this problem are desirable. The human nose easily distinguishes between horse-manure, pig- and

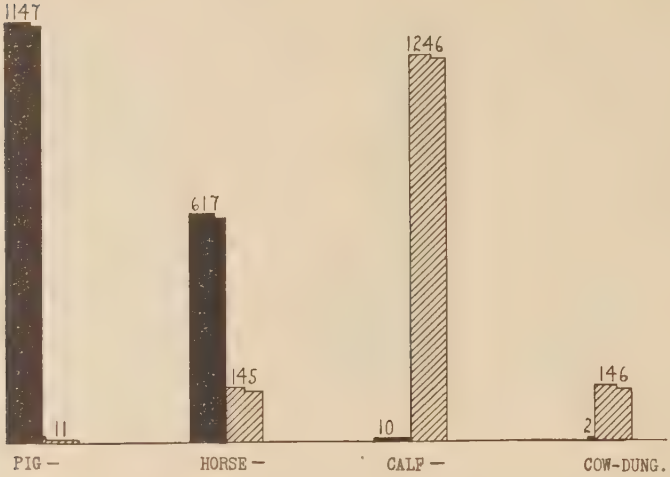

Fig. 3. Experiment No. 3. (See Table IV).

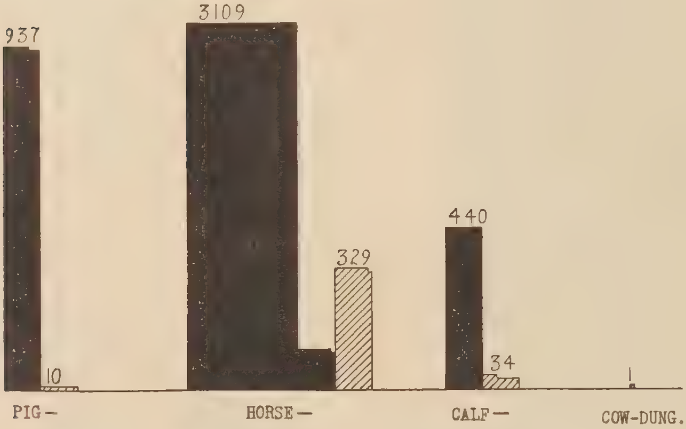

Fig. 4. Experiment No. 4. (See Table V).

cow-dung, each of which has a very characteristic smell ; thus it is not surprising that the flies also distinguish between them. Even cow-dung and calf-dung smell somewhat differently to us, and the experiments show that several species of flies, including *Musca* and *Stomoxys*, are differently influenced by these two substances. The difference is so considerable that it cannot be due to accidental circumstances or experimental errors, and further it agrees with the observations previously made. This must be attributable to a difference in the chemical and biological composition of the dung. As we have not analysed the dung we cannot state what accounts for this difference ; but most probably it is chiefly caused by the varying composition of the food of calves and adult cattle, and particularly by the fact that the calves used in our experiments were all fed on milk. Not only must we presume that milk gives another chemical composition to the faeces, but also that the flora and fauna of the faeces will be different from that produced by a purely vegetable fodder.

Unpublished investigations made in Denmark by Professor M. Christiansen (State Veterinary Serum Laboratory) show that the bacterial flora of the excreta of young milk-fed calves consisted mainly of *Bacillus coli*, while in cow-dung *Micrococci* predominated and *coli* were few.*

There is a marked difference in the temperatures of the different kinds of manure. In manure-pits with a considerable quantity of manure the temperature of horse-manure may rise to 70–80°C. or more, that of the pig-dung to 60–70°C., while the cow-dung generally keeps a temperature of 20–30°C. Farmers rightly call cow-dung a "cold dung." Measurements of the temperature in the vessels containing dung used in our experiments show a corresponding order, though the absolute temperatures reached are lower on account of the smaller quantities. To exemplify this we give the temperatures from experiment II (Table I).

TABLE I.

Measurement of Temperature (Centig.) in Vessels containing Manure.

Jar No.	28.vi.	29.vi.	30.vi.	1.vii.	3.vii.	4.vii.	5.vii.	6.vii.
1 Pig	22	25	27	33	29	28	28	28
2 Pig	21	24	24	25	26	24	25	26
3 Horse	28	32	32	31	30	29	29	30
4 Horse	25	33	32	29	29	29	29	31
5 Calf	16	22	23	21	24	25	25	26
6 Calf	19	23	24	23	26	26	26	26
7 Cow	16	18	18	19	20	19	20	20
8 Cow	16	18	19	18	20	18	20	21
9 Pig	24	27	38	37	31	31	31	31
10 Pig	21	27	36	34	28	27	27	27
11 Horse	28	32	35	38	32	29	30	31
12 Horse	29	37	41	37	32	31	31	31
13 Calf	17	23	23	23	23	25	24	26
17 Calf	19	23	24	25	26	24	24	26
15 Cow	17	18	18	18	18	19	20	20
16 Cow	16	18	18	18	18	18	20	21
Air	18	18	18·5	16·5	19	19	21	22

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* I am grateful to Professor Christiansen for permission to mention these data.

TABLE II.

EXPERIMENT I.

Faurholm 8–9.vi.1933

Species	A. Open-air series								B. Calf-stable series								Number of flies from				Total
	Jar No.								Jar No.												
	1P	2P	3H	4H	5Ca	6Ca	7Cw	8Cw	9P	10P	11H	12H	13Ca	14Ca	15 Cw	16 Cw	Pig-dung	Horse-dung	Calf-dung	Cow-dung	
Musca domestica ...	81	157	512	844		1			26		834	12	1	1			264	2,202	3		2,469
Muscina stabulans ...	3	4							10	2							19				19
Myiospila meditabunda		5					1										5			1	6
Morellia hortorum ...					16		30						27	6	13	97			49	140	189
Stomoxys calcitrans ...			133	138	29	66					13	54	170	31				338	296		634
Hydrotaea dentipes ...	3	45	1	2					164		51	1					212	55			267
,, *armipes* ...			4	16	58	71	8	2			182	197	7	39	1	2		399	177	13	589
Fannia canicularis ...			2	1														3			3
Paregle cinerella ...		2															2				2
Scatophaga stercoraria				2														2			2
Sepsis sp.				+	+	+	+	+	+				+	+	+		+	+	+	+	
Sphaerocera subsultans		+			+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	
Limosina sp. ...	+	+	+	+	+	+	+	+	+		+		+	+	+	+	+	+	+	+	
Scatopse sp.			+															+			
Sciara (Lycoria) sp. ...				+	+	+					+			+				+	+		

TABLE III.

Experiment II.

Faurholm, 27–28.vi.1933

Species	A. Open-air series								B. Pig-sty series							Number of flies from					Total
	Jar No.								Jar No.												
	1P	2P	3H	4H	5Ca	6Ca	7Cw	8Cw	9P	10P	11H	12H	13Ca	14Ca	15 Cw	16 Cw	Pig-dung	Horse-dung	Calf-dung	Cow-dung	
Musca domestica ...	2,526	128	390	1	8	16			8,097	1,366	1,682	534	18	27			12,117	2,607	69		14,793
Muscina stabulans ...	35	27				3			8	2				2	30		72		5	30	107
Stomoxys calcitrans ...	2				3	199			6	9	3		212	4			17	3	418		438
Hydrotaea dentipes ...									5				2	3			5	5			10
,, *armipes* ...			8	3	26	7				5			12	2			5	11	47		63
Ophyra leucostoma ...		9															9				9
Fannia canicularis ...	1	2							3			4					6	4			10
,, *scalaris* ...	2								11								13				13
Sepsis sp.	+	+			+	+								+			+		+		
Drosophila sp. ...		+				+			+								+		+		
Sphaerocera subsultans		+			+	+		+				+	+		+	+	+	+	+	+	
Limosina sp. ...	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	
Scatopse sp. ...		+															+				
Pericoma sp. ...						+													+		

TABLE IV.

Experiment III.

Faurholm, 28–29.vii.1933

Species	A. Open-air series								B. Calf-house series								Number of flies from				Total
	Jar No.								Jar No.												
	1P	2P	3H	4H	5Ca	6Ca	7Cw*	8Cw*	9P	10P	11H	12H	13Ca	14Ca	15 Cw*	16 Cw*	Pig-dung	Horse-dung	Calf-dung	Cow-dung*	
Musca domestica ...	5	704			6	2			365	73		617	2		1	1	1,147	617	10	2	1,776
Muscina stabulans ...	9	15							14						3		38			3	41
,, *pabulorum*...									2								2				2
Myiospila meditabunda						3													3		3
Stomoxys calcitrans ...	3	1	9	11	401	379	15	9	2	5	51	76	268	198	60	62	11	145	1,246	146	1,548
Haematobia stimulans											2	6				1		8		1	9
Hydrotaea dentipes ...		2						23	143	13							158			23	181
,, *armipes* ...	18					1	40	2	4		106	38	6	2	4		22	144	49	6	221
Ophyra leucostoma ...									2								2				2
Fannia canicularis ...	12					1			1								13		1		14
,, *scalaris* ...		14															14				14
Paregle cinerella ...	4	4			13	3	9	8	8								16		16	17	49
Scatophaga stercoraria							3													3	3
Sepsis sp.	+	+			+	+	+	+	+	+			+	+		+	+		+	+	
Sphaerocera subsultans	+	+					+	+		+				+	+	+	+		+	+	
Limosina sp. ...	+		+	+	+	+	+	+			+	+	+	+	+	+	+	+	+	+	
Scatopse sp. ...					+										+				+	+	
Sciara (Lycoria) sp.						+													+		
Pericoma sp. ...			+	+														+			

* More precisely dung of bullocks.

TABLE V.

EXPERIMENT IV.

Tune, 27–28. viii. 1933.

Species	A. Open-air series								B. Pig-sty series								Number of flies from				Total
	Jar No.								Jar No.												
	1P	2P	3H	4H	5Ca	6Ca	7Cw	8Cw	9P	10P	11H	12H	13Ca	14Ca	15 Cw	16 Cw	Pig-dung	Horse-dung	Calf-dung	Cow-dung	
Musca domestica ...	1	126	1,759	1,315	3	3			708	102	34	1	432	2			937	3,109	440		4,486
Muscina stabulans ...	124								31	1							156				156
Myiospila meditabunda							5	3					2		1				2	9	11
Stomoxys calcitrans ...			153	62		10		1	9	1	75	39	2	22			10	329	34	1	374
Haematobia stimulans									1								1				1
Hydrotaea dentipes ...	204	13	28	45	85	95			1	3	28	29					221	130	180		531
Ophyra leucostoma ...									19	20							39				39
Fannia canicularis ...	115	61	1	80	90	107			4	6	2	5	4	2			186	88	203		477
,, *scalaris* ...	731	1,079			32	252			5	3	1			2			1,818	1	286		2,105
Paregle cinerella ...							1						4						4	1	5
Lucillia sp. ...									14								14				14
Scatophaga stercoraria							34	105							43	245				427	427
Sepsis sp.								+		+			+				+		+	+	
Sphaerocera subsultans							+	+		+		+		+			+	+	+	+	
Limosina sp. ...	+	+			+	+	+	+		+	+	+	+	+			+	+	+	+	
Scatopse sp. ...		+	+	+								+		+			+	+	+		

The cause of this characteristic difference of temperature must be sought in the different texture, chemical composition and microbial flora. Most remarkable is the difference in the temperature of cow- and calf-dung which we have confirmed during other investigations ; this difference might perhaps contribute to the different preferences of the flies for these two kinds of manure.

In the following notes the reactions of the different species during the experiments will be discussed.

MUSCIDAE.

Musca domestica, L.

A glance at the graphs reveals the vital importance of horse-manure and pig-dung to the development of this species. If pregnant house-flies are free to choose they will concentrate round the vessels containing these manures, while a smaller number of eggs will be laid in calf-dung, and none in cow-dung. All four experiments agree on this point.*

The results tend to show that there is no essential difference between horse-manure and pig-dung as regards their power to attract the ovipositing flies. In experiments I and IV horse-manure yielded the largest number of individuals, in experiments II and III pig-dung was preferred. Most remarkable is the enormous quantity of house-flies produced by the pig-dung in experiment II, in which the vessels with pig-dung produced altogether 12,117 *M. domestica*, and the horse-manure 2,607.

Thus the experiments corroborate the view gained during observations on the farms, that pig-dung is highly favoured as a medium for egg-laying. In practice on Danish farms it will certainly become of far greater importance to fly-production than horse-manure, because under normal conditions far greater quantities of pig-dung than of horse-manure will be carried to the dump. The number of pigs in Denmark in 1933 was about 4 millions, whereas only about half-a-million horses were kept. It is true that a horse produces about 2½ times as much manure as a pig, but in summer the cart-horses are kept in the open for many hours each day, whereas the pigs in Denmark are mostly kept in sties ; the consequence is that generally a considerably larger quantity of pig-dung than of horse-manure is carried to the manure-pit. The total production of pig-dung in Denmark in 1934 may be estimated at 4·8 million tons.

It appears from a review of the literature that the importance of pig-dung in fly production has been greatly underestimated previously. No doubt this is connected with the fact that most of the investigations have been made either in towns or in military camps, where horse-manure is almost exclusively involved. Investigations in recent years in Hungary (Lörincz & Makara 1934 and 1935) and observations not yet published made in Spain (Cano & Collado) have, however, confirmed our view as to the importance of pig-dung under rural conditions.

Lörincz & Makara have further proved, by very interesting experiments, that the different kinds of manure not only vary much in their power to attract egg-laying flies but also in their value as a breeding medium. They have studied the maximum number of flies which can be produced by 1 kg. of fresh dung and have found the following figures :—

Pig-manure	120 gr. pupae	=	7,500 [? 8,000]	normal-sized flies
Horse-manure	75 gr.	=	5,000	,, ,,
Cow-manure	30 gr.	=	2,000	,, ,,

---

* We have found in other experiments that the house-fly is able to carry through its development in cow-dung, so that the remarkable absence of this fly from our vessels with cow-dung cannot be explained by a hypothetical larval mortality, but only by an absence of oviposition in this dung.

By overcharging a given weight of a certain kind of manure they obtained a greater number of flies than those given above, but the flies were of considerably smaller size, down to really dwarf flies of an individual pupal weight of only 0·4–0·5 ctgr., the normal weight being 1·5 ctgr., while the maximum was 2·5 ctgr. In our own experiments we found that the average size of house-flies from pig-manure was larger than that of flies from horse-manure, especially when a great number of flies hatched from a certain jar.

Further Lörincz & Makara have shown that the fly-breeding capacity of the manure diminishes with the progress of fermentation, but that pig-manure retains its capacity for fly-breeding much longer than do horse- and cow-manure.

These observations added to our own make it safe to say that pig-dung—when present—is from all points of view the most important breeding medium of the house-fly.

In our experiments the house-fly did not lay any eggs in cow-dung (except in experiment III, where two individuals hatched), and during our observations in practice we have only in two or three cases found larvae in this dung in numbers worthy of mention (*cf.* above). This circumstance is of considerable practical interest, in the first place because on most farms cow-dung constitutes the bulk of the dung, secondly, because we have been able to utilise the unattractiveness of cow-dung in a simple method of control (Thomsen, 1934). Earlier investigators too (particularly Patton) have pointed out that cow-dung is of slight importance to the oviposition of *M. domestica.*

Lörincz & Makara have obtained different results during their investigations in Hungary ; by experiment they found that *M. domestica* did deposit its eggs in cow-dung, and observations on farms showed that under conditions prevailing in Hungary cow-dung plays an important part as a breeding medium.

Investigations are being made in order to clarify the cause of this strange difference between conditions in Hungary and Denmark, which is of vital importance from the point of view of control ; in the present report we shall confine ourselves to mention the possibility that the Hungarian house-flies might comprise a mixed population of *M. domestica*, L., and the very nearly related species or race *M. vicina*, Macq., which according to Patton's observations (in contrast to *M. domestica*) is able to breed in cow-dung (Patton, ii, 1931, p. 596). Closer investigations on the distribution in Europe of this race would be desirable, and the possibility should also be contemplated that *M. domestica* might include other races, which differ biologically, as has been demonstrated for several other insects (for instance *Culex pipiens* and *Anopheles maculipennis*).

It is possible to construct graphs from the hatching figures for each day which show the duration of development ; and as we registered the temperature in the individual vessels, it might be possible to draw some conclusions as to the dependence of development on temperature. As, however, we have studied this problem very closely by exact experiments in incubators, which yield far more reliable values, we shall not reproduce the graphs from the experiments dealt with here. It should, however, be noted that the curves have very pronounced tops with a very steep rise, as the maximum number will emerge a few days after the appearance of the first flies in the cylinders. In experiments I, III and IV the maximum number in the vessels with horse-manure was reached 4 to 5 days before the maximum of the pig-dung, owing to the somewhat higher temperature of horse-manure ; in experiment II, however, the maxima of horse-manure and pig-dung coincide, because in this experiment the pig-dung had a higher temperature than usual, most likely on account of the very large number of larvae in it. We have many times observed that overcrowding in a breeding jar causes a rise of temperature of 2 to 3°, in extreme cases 5–6° (*cf.* Hase 1935).

At a temperature of 22°C. the duration of development was about 24 days ; at 23°, 22 days ; at 24°, 19 to 20 days ; at 27°, 16 to 17 days ; and at 30°, 14 to 15 days ; the temperature given being the average for the period.

A comparison with the results obtained in the incubator experiments shows that these determinations are far from being exact, the minimum time required for development at a certain temperature in the incubator experiments being considerably shorter than in the oviposition experiments ; thus at 30° the minimum is 9 days, at 25° 12 days and so on. This was to be expected, as the conditions of the larvae and pupae in the big vessels in the oviposition experiments must necessarily in several points deviate from the optimal conditions which produce a minimum duration of development.

Stomoxys calcitrans, L.

Figs. 1–4 and Tables II–V show that in our experiments *Stomoxys* preferred egg-laying in horse-manure and calf-dung, while only an inconsiderable number of eggs were deposited in pig- and cow-dung. In experiments I, III and IV, the vessels with horse-manure yielded the greatest number of *Stomoxys*, in experiment II the greatest number hatched in the calf-dung ; but the difference between the figures for the two kinds in experiment I is only slight. Altogether the number of hatched *Stomoxys* is considerably smaller than the number of *Musca domestica*, which agrees with the general impression that *Stomoxys* is somewhat less reproductive, but other circumstances may perhaps be involved. *Stomoxys* stands second as regards number of individuals, except in experiment IV, where it is surpassed by *Fannia scalaris*.

As regards calf-dung our experiments agree strikingly with the general observations, which showed that the calf-stalls in practice have the greatest production of *Stomoxys*. As to horse-manure, however, the results of the experiments are not wholly in harmony with our observations on farms, where *Stomoxys* was only rarely found in this kind of dung. This inconsistency may be attributed to several causes. It seems that *Stomoxys* does not appreciate quite fresh manure, so that the excrement dropped in the stalls of ordinary horse-stables, which are cleaned daily, does not count much as breeding material. On the other hand, we should expect that the manure in horse-boxes, where it is often allowed to remain for some time, would be highly suitable for a breeding-place. The importance of these places is, however, limited by the fact that stable-flies are as a rule present only in small numbers in horse-stables, but concentrate in cattle-sheds, partly because they prefer the blood of cattle to that of other animals, partly because there will often be a higher and more suitable temperature in the byre than in the stable. Thus food- and temperature-preferences will tend to keep *Stomoxys* in the cattle-sheds, and as they will usually find sufficient material for oviposition here they have no impulse to seek horse-manure. Where horse-manure is stored in larger quantities the high temperature produced by fermentation will probably often be deterrent to the oviposition of *Stomoxys*.

That pig-dung attracts *Stomoxys* only to a slight degree for egg-laying agrees with the observations made.

It is noteworthy that in our experiments pure cow-dung was so little attractive to *Stomoxys*. In experiments I and II not a single *Stomoxys* hatched from the vessels with cow-dung ; in experiment IV only a single individual, and only experiment III forms an exception, altogether 146 *Stomoxys* hatching from the 4 vessels with cow-dung. It should, however, be borne in mind that the dung in experiment III originated from bullocks and not from milk-cows, so that it may have been of a different texture from that in the other experiments. It may be objected that eggs might have been deposited in the cow-dung, but that the eggs or larvae had perished. Against this supposition, in the first place, is the fact that in other experiments we have found that *Stomoxys* may develop normally in pure cow-dung ; secondly, that in the vessels with cow-dung other species of flies hatched in fairly considerable numbers.

As mentioned above, the literature gives rather diverging views on the breeding materials of *Stomoxys* ; as regards cow-dung we agree, however, with Portschinsky and Bishopp, who seem to have made the most thorough investigations on the biology of the larva.

The duration of the development of *Stomoxys* in the vessels was rather variable, and as we have obtained fully reliable data from incubator experiments, which will be published later, there is no need to mention the incorrect figures obtained in this investigation.

Muscina stabulans, Fall.

This well-known species is a typical house-insect, occurring in small numbers in and about rooms and stables ; it will hardly move far from houses or farms. Of a total number of 323 *M. stabulans* hatched in our vessels, 285, or 88 per cent., hatched from pig-dung, the rest from cow-dung and calf-dung.

The literature contains a number of statements as to the hatching of *M. stabulans* from various decaying animal and vegetable substances (Keilin, 1917, p. 415–421 ; Séguy, 1923, a and b). Portschinsky in 1913 established the fact that the older larvae (from the end of the second stage) are carnivorous and particularly attack other fly larvae which live in the same substances (for instance the larvae of *Musca domestica* and *Hydrotaea dentipes*), whereas the *Muscina* larvae themselves are devoured by the larvae of *Polietes albolineata*. In view of this it is remarkable that the jar which produced the largest number of *Muscina stabulans* in our experiments, namely 124 (1P in experiment IV), also gave 204 *Hydrotaea dentipes*, but only a single *M. domestica*, no doubt because the larvae of this species were eaten up by the zoophagous larvae of the two other species. It should be noted that Séguy (1923 b) maintains that if vegetable food is plentiful, the larvae will not become zoophagous in the third instar.

Our observations show the following minimum figures for the duration of development :—24°–31° (mainly 31°), 13 days ; 21°–26° (mainly 24°–25°), 14 days ; 15°–21° (mainly 20°), 20 days ; 14°–20° (mainly 19°), 21 days ; 13°–20° (mainly 18°), 23 days. As stated on p. 578 (para. 2) these figures are not really reliable, but so long as none more exact are available they may be of some interest. The same thing applies to the following species.

We have found adult females hibernating in cool places in houses (Holti, Villingebœk).

The closely related species *M. pabulorum*, Fall., hatched from pig-dung in experiment III, but only two individuals. The habits of its larvae are supposed to be the same as those of *M. stabulans* (Keilin, 1917).

Myiospila meditabunda, F.

This species hatched in experiments I, III and IV, in small numbers from pig-, calf- and cow-dung. Howard (1900) hatched it from human faeces ; Portschinsky (1910) from cattle-dung, human faeces and rarely from horse-manure ; Keilin (1917) found the larvae in cow-dung and pig-dung.

These data do not, however, according to our experience, give a true aspect of the biology of the species. In 1934 and 1935 we made regular investigations of the flies occurring on pasturing cattle and on cow-droppings, and we found that *Myiospila meditabunda* is one of the most constantly occurring members of the fly fauna of the latter ; we have never observed the adult flies except on cow-droppings scattered in the field, and not on the cows themselves. The number of individuals is always fairly small, only 2 to 3 on a single cow-dropping, in which they lay their eggs. Their development has been described by Portschinsky and Keilin, who have demonstrated that these larvae, too, are saprophagous in their first stages, but in and from the third stage they become zoophagous and feed on other fly larvae.

In our jar experiments the duration of the development at 14–20°C. (mainly 19–20°) was 21 days, and at 15–19°C. 28 days. In a single incubator experiment we found that at a constant temperature of 25°C. the length of development was 17 days.

Morellia hortorum, Fall.

A number of individuals of this species appeared in experiment I, namely 140 from cow-dung and 49 from calf-dung. Part of them may, however, be *M. simplex*, Loew, as only the males can be determined with certainty.

Adult *Morellia* have been observed many times, partly on the window-sills of cattle-stalls, but more particularly on pasturing cattle, where they lead a life similar to that of *Musca autumnalis*, sucking eye-secretions and blood from wounds and from the holes produced by the bites of TABANIDAE and STOMOXYDINAE. So far as we know, this peculiar habit has not been mentioned anywhere in literature ; we intend, however, to treat the fly-fauna associated with cattle more in detail in another paper. The oviposition of *Morellia* takes place principally in cow-droppings.

In our jar experiments the development lasted for a minimum of 20 days at 14°–21° (mainly 19°–20°), and 22 days at 13°–19° (mainly 18°). In a single incubator experiment the duration of development was 17 days at 22°.

Mellor (1919) has bred *M. hortorum* from hibernating pupae found in cow-manure.

Haematobia stimulans, Meig.

A few individuals of this species hatched in experiment III and IV from pig-dung, horse- and cow-manure. This occurrence must, however, be regarded as quite accidental, as this species is a blood-sucking Stomoxydine, which will almost exclusively suck the blood of pasturing cattle and deposit its eggs in fresh cow-droppings (Thomsen 1935).

ANTHOMYIDAE.

Hydrotaea dentipes, F.

H. dentipes occurred in all four experiments and in all four kinds of manure, the greatest number hatching from pig-dung. Further, during our general observations on the farms we have very often found the larvae both in the open in manure-heaps (particularly in pig-dung) and indoors in calf-boxes. Once we found larvae in large numbers in ensilage (lucerne).

The adult fly is seen now and then in pig-sties and calf-sheds ; it seems to have a marked preference for houses and sheds. It should be pointed out that we never saw this species on the skin of cattle (either in stables or in the field), whereas a number of other *Hydrotaea* species are associated with domestic animals, particularly cows, leading a life similar to that of *Musca autumnalis* and *Morellia* ; nor have we observed that *H. dentipes* annoys man.

Presumably the adults hibernate in stables, but larval development may also be continued throughout the winter in stables with favourable temperature conditions. Thus on 12.i.1933 we found many larvae of *H. dentipes* in a calf-shed (Wedellsborg). Also Mellor (1919) has found larvae and pupae during the winter.

As will be known, Portschinsky (1910) found that the larvae of *H. dentipes* are saprophagous in the two first stages, but in the third stage become zoophagous, like *Muscina stabulans* and *Myiospila meditabunda*. According to this author the larvae of *H. dentipes* feed on the larvae of *Musca domestica, Stomoxys calcitrans, Lucilia* and others, but succumb to the more vigorous larvae of *Muscina stabulans* and *Polietes albolineata*. This has been confirmed by Keilin (1917).

The figures obtained from our experiments agree well with this experience, in several cases it is clearly seen that a great number of *Hydrotaea* (*dentipes* or *armipes*) from a particular jar is accompanied by a comparatively small number of *M. domestica* and *Stomoxys*, and conversely (most distinct in experiment IV).

On the other hand, it looks as if the number of *Fannia* is independent of the presence of the zoophagous larvae ; probably the *Fannia* larvae owing to their heavier chitinisation and their forked lateral setae are better protected against the attacks of the carnivorous species.

Our determinations of the duration of development are very unreliable. At 16°–28° we found that development took 23 days, at 19°–23° (mainly 22°) 24 days, at 19°–21° 25 days, but a longer duration is common. It is natural that the zoophagous mode of feeding should cause considerable fluctuations in the time of development.

Hydrotaea armipes, Fall.

This species hatched in fairly large numbers in experiments I, II and III (Faurholm), but we have never observed it on other occasions, not even on the same farm. Eggs have been laid both in the open and indoors in all four kinds of dung, mostly in horse-manure, with calf-dung second.

Knowledge of the biology of this species is scanty. Bouché (Séguy 1923 a) is said to have found the larvae in cow-dung in the autumn. Portschinsky (1910) records that he has found the larva in horse- and cow-dung, mainly in the former ; he states that it is zoophagous like the larva of *H. dentipes*.

The duration of development in the jars at a temperature of 16°–26° (mainly 24°) was 25 days, at 16°–28° (mainly 21°–22°) 26 days, at 14°–20° (mainly 18°–19°) 27 days.

Ophyra leucostoma, Wied.

In experiments II, III and IV, some individuals of this species emerged in the vessels with pig-dung, the greatest number in the vessels exposed to oviposition outdoors. Besides, we have a few times captured the adult flies in stables or in the near vicinity of these ; they have been observed from the beginning of June to the end of September. The only place however where we have observed the species in abundance is on a farm near Copenhagen, where the pig-dung was placed in a closed shed ; this arrangement was made by order of the municipal authorities, because the neighbours in this rather crowded district had complained of the stench from the manure-pit. In this manure-shed two species of flies were abundant, *Ophyra leucostoma*, and the somewhat larger blue-black Calliphorine species, *Phormia terrae-novae* : the larvae of both species occurred in vast numbers in the pig-dung. This is the only case among the numerous farms investigated by us where larvae of species other than *Musca domestica* have been predominant in pig-dung. As it is stated that the larvae of *O. leucostoma* are zoophagous (Séguy 1923 a), it is possible that they entirely destroyed all the *Musca* larvae in this place.

Graham-Smith (1916) states that this species hibernates as a pupa in the earth.

Fannia canicularis, L.

" The Lesser House-Fly " emerged from the vessels with pig-dung, calf-dung and horse-manure (but not cow-dung), the majority hatching in experiment IV, which was carried out at Tune Agricultural School, where we also observed the adult flies in larger numbers than in other places (in a pig-sty). In the experiments it oviposited both indoors and outdoors, in experiment IV mostly outdoors. This species occurred on practically all the examined farms, in dwelling-rooms and more frequently in pig-sties or calf-stalls, where in its well-known way it will circle round the lights or sit on the pillars. More rarely we met it in cow-houses. Flies have been bred from different kinds of manure, besides those already mentioned, thus in August 1933 from the dung of white mice, and in July 1932 from chicken-dung. The literature also records the occurrence of this larva in numerous other decaying or fermenting substances and excrements (*cf.* for instance Howard 1900, Hewitt 1914, Séguy 1923 a).

In the experiments the shortest duration of development was 18 days at a temperature of 21°–26°C, and 21 days at 18°–23° (mainly 22°).

Fannia scalaris, Fab.

" The Latrine Fly " in experiments II and III emerged in scanty numbers, and exclusively from pig-dung. In experiment IV, in which as stated above vessels were exposed to oviposition at Tune Agricultural School, this species hatched in vast numbers, altogether 2,105, of which the bulk (1,818) was produced by pig-dung, 286 by calf-dung, and only 1 by horse-dung. By far the greatest number of eggs was deposited in the open. On the other occasions, too, we have found these larvae in pig-dung and bred them. It may be that the preference of this species for pig-dung in our experiments is to some extent due to the considerable content of water of this dung, as *Fannia* larvae seem on the whole to prefer semi-liquid substances ; it should however be pointed out that in none of our experiments did *Fannia* hatch from cow-dung, which also has a considerable content of water ; thus other qualities of the dung (odorous substances, and perhaps temperature) must have been involved.

Adults are common in stables, mainly in pig-sties and calf-stables, where they circle around the lamps like *F. canicularis.* Both species seem to occur in stables all the year round, but Mellor (1919) has recorded the hibernation of larvae too. *F. scalaris* is rarely met with in dwelling-houses.

In our experiments the minimum duration of development at a temperature of 18°–23°C. was 23 days, at 18°–24° 24 days. In the laboratory we once ascertained a length of development of 26–27 days at 19°–21°C. (eggs and newly-hatched larvae were observed 30th May, pupae 13th June and flies 25th June).

Hewitt (1914) records that *F. scalaris* breeds in substances similar to those used by *F. canicularis,* but prefers excreta, and often breeds in human faeces, sometimes in decaying fungi. Parker (1918) refers to it as the most frequent species of the flies occurring in " privy vaults " (Montana, U.S.A.). Lesne (1921) states that this fly is one of the commonest species in closed latrine pits with liquid or semi-liquid faeces (environs of Paris).

Paregle cinerella, Fallén.

Of this Anthomyid a number of individuals emerged in experiments I, III and IV, from pig-, calf- and cow-dung. In other experiments we have observed larvae of this species in great numbers (thousands) in cow- and pig-dung, and egg-laying flies were observed on the heaps of manure in the same experiments. The adult was seen a few times on cow-droppings scattered in the field. According to our notes we have observed adult flies from the end of May till the middle of September, generally 5 to 15 individuals at each observation. This fly seems to occur mainly in the open, but we have also observed it a few times in stables.

The minimal duration of development in the jar experiments at a temperature of 14°–20° (mainly 19°–20°) was 13 days, at 18°–23° (mainly 21°–22°) 15 days. Thus it has a more rapid development than most other species.

In the literature we have found only scanty information on the biology of this common species. Mellor (1919) found pupae in cow-dung in October 1916; the flies emerged in March and May of the next year. Karl (1928) mentions that the larva has been observed in human faeces. To the same genus (generally considered a subgenus of *Chortophila*) belongs *P. radicum*, L., the larva of which has been found both in roots of crucifers and in decaying substances, including dung (Hewitt 1907).

Calliphoridae.

Lucilia sp.

In experiment IV, 14 *Lucilia* emerged from pig-dung. The males were determinable by their genitalia and proved to belong to the two species *L. simulatrix*, Pand., and *L. sericata*, Meig. The specific characters given for the females do not allow of any safe determination, but most likely they belong to the same two species, which are known to breed in dung. On several other occasions we have seen *Lucilia* females on pig-dung and found their eggs, which are laid in batches of about 50 (rather superficially), in the dung. The larvae too have been found in pig-dung, where they live rather scattered, apparently not in great numbers.

As is well known, the same two *Lucilia* species and several others lay their eggs in carcases and sometimes—at any rate so far as *L. sericata* is concerned—also on the skin of living animals (sheep, etc.).

Scatomyzidae (Cordyluridae).

Scatophaga stercoraria, L.

This species hatched in rather large numbers from cow-dung in experiment IV; further, in experiment III, three individuals occurred in cow-dung and two in horse-manure. The latter occurrence must, however, be considered accidental, as this species is otherwise a typical cow-dung insect, which will deposit its eggs both in cow-droppings scattered in the field, and in fresh cow-dung in a heap of manure.

Our investigations of the flies breeding in cow-droppings revealed that the adult flies occur in two periods which possibly represent two generations: they are frequent in April–May, decrease in numbers in June, and from the end of this month till the middle of August they have quite disappeared (or only a few individuals are seen); late in August they again increase, and in September and the beginning of October they will generally be frequent, and even in the middle of November they may be observed on cow-droppings. It will be seen that the abundance of *Scatophaga* in experiment IV started in the last days of August, which agrees well with our field observations.

Sepsidae.

Sepsis sp.

Sepsis and several other small Diptera, which will be discussed below, appeared in such vast numbers in many of the vessels that we gave up counting the individuals, and in the tables we have only stated the presence of the particular species by a +; as a rule, this means that it is present in great numbers. Probably there is only one species of *Sepsis*, which we have not been able to identify as yet.

The tables show that *Sepsis* emerged from all kinds of dung, with oviposition both indoors and outdoors. We have, however, only rarely observed *Sepsis* in stables, whereas it is common in the open from April till October, both in manure-pits and on cow-droppings in the field. We have found it most plentiful on cow- and calf-dung, less abundant on pig-dung, and least numerous on horse-manure. They move briskly about on the dung, periodically swinging their wings and abdomens in a very characteristic manner. The egg, which is figured by Portschinsky, is provided with a long, flagellum-like appendage rising over the surface of the dung. As the eggs are forced into the humid dung, which is poor in oxygen (observed in July 1933), the appendage must certainly have a respiratory function.

The minimum length of development in our vessels at a temperature of 19°–26° (mainly 24°–25°) was 13 days, at 21°–26° (mainly 22°) 14 days, at 14°–21° (mainly about 19°) 16 days, and at 16°–24° (mainly 17°–18°) 17 days.

DROSOPHILIDAE.

Drosophila sp.

A *Drosophila* emerged from pig-dung and calf-dung in experiment II. At a temperature of 24°–38° (mainly 31°) the development lasted 12 days, at 19°–26° (mainly 25°–26°) the minimum duration was 14 days.

Adults were present in almost all the pig-houses examined by us. We have mostly observed them during the winter months, but this may be casual. However, they are active during the winter and seem to oviposit freely during this season, at least we found eggs on 14th March 1935, and on several occasions we have observed larvae in winter.

This species breeds in small remnants of dung, moist fodder and the like, in corners and hidden places of the pig-house ; thus larvae and pupae are often found below the wooden platforms of the sty and below wooden gutter-covers.

BORBORIDAE.

Sphaerocera subsultans, Meig.

This is the largest species of the BORBORIDAE occurring in manure. It emerged from all kinds of manure in our vessels, but in by far the greatest numbers from calf-dung, then comes cow-dung, while horse- and pig-dung are much inferior in number of individuals. In our jar experiments many eggs were laid both in the open and in the stables, but to judge from our general observations it is fairly rare indoors, and must be considered a typical outdoor insect.

Adult flies can be observed all the year round in manure-pits, also during the winter. Mellor (1919) has made a similar statement as to *Borborus equinus*. We have observed *Sphaerocera* on the following dates : 28.i.34 (both adult flies and larvae), 14.iv.34, 11.v.33, 8.vi.33, 27.vii.33, 28.viii.33 and 8.xi.32.

The minimum duration of development at a temperature of 18°–20° was 14–15 days and at 23°–24° 12 to 13 days.

Limosina sp.

This designation includes at least two species, a larger and a smaller one, which we have not been able to identify. They emerged from all four kinds of manure, but our observations show that they prefer horse-manure, then come pig- and calf-dung, while cow-dung only yielded a few individuals. Our jar experiments show that this fly oviposits both outdoors and indoors, which is corroborated by our general observations, as we have found the larvae in calf-boxes, under wooden gutter-boards (particularly in pig-sties). behind self-filling water-troughs and in other very humid places. However, outdoor oviposition seems to be more usual.

Limosina is also found on cow-droppings, but it seems to be another species.

At a temperature of 18°–19° the minimum duration of development was only 13 days.

Bibionidae.

Scatopse sp.

Scatopse sp. (*pulicaria*?) emerged from some of the vessels from all kinds of manure, in both series A and B. Besides we have bred this species from cow-droppings in a field near Aastrup, 26.ix.33, and we have observed it a few times in stables.

At a temperature of about 20°C. the development lasts 28–32 days.

Mycetophilidae.

Sciara (Lycoria) sp.

A species of this genus appeared from the vessels with horse- and calf-dung in experiment I from both the A and the B series, and in experiment III from a single jar with calf-dung. We have fairly often found *Sciara* larvae in stables, in unclean corners with humid remnants of dung or fodder, and we have bred the adult fly from the material brought home ; a few times we have found *Sciara* larvae in manure-pits or in cow-droppings. Apart from these bred specimens adults have only been observed (11.iv.34) on a pig-dump. Possibly it was the same species in all the cases.

At a temperature of 19°–22° the duration of development seems to be 19–22 days.

Psychodidae.

A Psychodid fly, no doubt a *Pericoma*, hatched from horse- and calf-dung in experiments I and II.

Further, we have several times observed *Pericoma* both indoors and outdoors, but most probably there are at least two species. Adults have been seen several times in pig-sties, even in winter, *e.g.*, on 27.ii.33 at Faurholm, where they were briskly flying about at a temperature of 8°C. No doubt they breed in all kinds of dung and humid fodder both in stables and manure-pits. Further, a *Pericoma* has been observed on cow-droppings in the field and bred from cow-droppings taken into the laboratory. Again, we have reared *Pericoma* from earth samples which in the autumn had been taken into the laboratory from fields on which cows had been pasturing earlier. This indicates that the species hibernates in the earth as a pupa (or larva).

Once we found these larvae in dog faeces.

In cow-droppings taken to the laboratory the duration of development at a temperature around 16°–24°, but fairly constant at 17°–18°, was only 18 days.

Summary.

Observations on a great number of farms in Denmark showed that during the summer *Musca domestica* breeds in the first place in the fresh pig-dung deposited in manure-pits (or heaps of manure), in the second place it breeds in the bedding of calf-stables, next in horse-boxes and pig-sties ; whereas the horse-manure in manure-pits (or heaps of manure) is of inferior importance for house-fly breeding under rural conditions in Denmark.

Stomoxys calcitrans breeds chiefly in the bedding of calf-boxes (litter mixed with dung and urine), to a much smaller extent in humid remains of straw, old fodder or other vegetable material left in corners and crevices of stables. *Stomoxys* larvae were only rarely found in horse-manure, pig-dung, and cow-dung. Oviposition in the open has not been observed and, if existing, is quantitatively of no importance.

Four experiments were made in which vessels with pig-dung, horse-dung, calf-dung and cow-dung were exposed to the oviposition of flies. By counting the

numbers of flies of different species which subsequently hatched from the vessels, the preference of each species for certain kinds of manure as media for oviposition was clearly demonstrated (Tables II–V and figs. 1–4). As regards *Musca domestica* the experiments tend to show that there is no essential difference between horse-manure and pig-dung in their power to attract the ovipositing flies, while calf-dung is far less attractive, and no eggs are laid in pure cow-dung. *Stomoxys* preferred oviposition in horse-manure and calf-dung ; only few eggs were laid in pig- and cow-dung. As to the other species the reader is referred to the text.

References.

Austen, E. E. (1928). The House-Fly, 3rd ed., Brit. Mus., Econ. Series, no. 1a.

Bishopp, F. C. (1931). The Stable Fly : How to prevent its annoyance and its losses to live stock.—Frmrs' Bull., no. 1097, U.S. Dep. Agric., No. 1097.

Graham-Smith, G. S. (1916). Observations on the habits and parasites of common flies.—Parasitology **8.**

Hase, A. (1935). Über Wärme entwicklung in Massensuchten von Insekten, etc.—Zool. Anz. **112.**

Hewitt, C. G. (1907–08). On the life-history of the Root-Maggot, *Anthomyia radicum*, Meigen.—J. Econ. Biol. **2.**

——. (1914). The House-Fly, *Musca domestica* Linn. Its structure, habits, development, relation to disease and control.—Cambridge.

Hindle, E. (1914). Flies in relation to disease. Blood-sucking Flies.—Cambridge.

Howard, L. O. (1900). A contribution to the study of the insect fauna of human excrement.—Proc. Wash. Acad. Sci. **2.**

——. (1911). The House Fly. Disease Carrier. 2nd edition, New York.

——. & Bishopp, F. C. (1927). The House Fly and how to suppress it.—Frmrs' Bull., U.S. Dep. Agric. 1708.

——. & Hutchison, R. H. (1915). House Flies.—*Ibid*, no. 679.

Karl, O. (1928). Zweiflügler oder Diptera. III : *Muscidae.*—Die Tierwelt Deutschlands, **13.** Teil.

Keilin, D. (1917). Recherches sur les Anthomyides à larves carnivores.—Parasitology **9.**

Lesne, P. (1921). La faune entomologique des fosses d'aisances de la région parisienne. Les Fannia scatophages.—Bull. Mus. Hist. nat. **27.**

Lörincz, F. & Makara, G. (1935). Observations and experiments on fly control and the biology of the house fly.—League of Nations, Health Organisation, C.H./Hyg. rur./E.H.5 (multigraph).

Madsen-Mygdal, T. (1915). Stuefluens Bekæmpelse paa Landet.—Vort Landbrug **34.**

Mellor, J. E. M. (1920). Observations on the habits of certain flies, especially of those breeding in manure.—Ann. Appl. Biol. **6.**

Mitzmain, M. B. (1913). The bionomics of *Stomoxys calcitrans* Linnaeus, a preliminary account.—Philipp. J. Sci. (B.) **8.**

Newstead, R. (1905–06). On the life-history of *Stomoxys calcitrans* Linn.—J. Econ. Biol. **1.**

Nieschulz, O. (1933). Ueber die Bedeutung der Vorzugstemperatur von Insekten (besonders von Fliegen und Mücken).—Zool. Anz. **103.**

——. (1933). Over de reactie van *Stomoxys* op verschillende temperaturen.—Ned.-Indische Bladen voor Diergeneeskunde **45.**

PARKER, R. H. (1918). Data concerning flies that frequent privy vaults in Montana (Dipt.).—Ent. News **29.**

PATTON, W. S. (1931). Insects, Ticks, Mites, and Venomous Animals of Medical and Veterinary Importance. Part II, Public Health.

PORTSCHINSKY, I. A. (1910). Recherches biologiques sur le *Stomoxys calcitrans* L., et biologie comparée des mouches coprophages.—Work Appl. Ent. (Mem. Bur. Ent. Sci. Comm. Centr. Bd. Land Adm. Agric.), **8,** no. 8.

——. (1913). *Muscina stabulans* Fall.—*Ibid.* **10,** no. 1.

ROUBAUD, E. (1915). Production et auto-destruction par le fumier de cheval des mouches domestiques.—C. R. Acad. Sci. Paris **161.**

SÉGUY, E. (1923). Diptères Anthomyides.—Faune de France, Paris.

——, E. (1923). Etude sur le *Muscina stabulans* Fallén (Diptère).—Bull. Mus. Hist. nat. **29.**

——, E. (1933). La Mouche charbonneuse (*Stomoxys*).—Terre et la Vie, **3,** no. 7.

SURCOUF, J. M. R. (1921). 1° Note sur la biologie de *Stomoxys calcitrans* L.—Bull. Mus. Hist. nat. **27.**

——. J. M. R. (1923). Deuxième note sur les conditions biologiques du *Stomoxys calcitrans* L.—*Ibid.* **29.**

THOMSEN, M. (1934). Fly control in Denmark.—Quart. Bull. League of Nations, **3.**

——. (1935). A comparative study of the development of the *Stomoxydinae* (especially *Haematobia stimulans* Meigen) with remarks on other coprophagous Muscids.—Proc. Zool. Soc. London.

WILHELMI, J. (1917). Die gemeine Stechfliege (Wadenstecher).—Monogr. Z. angew. Ent. no. 2.

FRUIT-PIERCING LEPIDOPTERA IN SIERRA LEONE.

By E. HARGREAVES, A.R.C.S., D.I.C.

Fruit-piercing Lepidoptera constitute an important problem in some parts of the world, such as Africa, Australia and India ; they also occur in Ceylon, Fiji, Dutch East Indies, Indo-China, Japan, Malaya, Samoa, and South America.

In Sierra Leone, grape-fruit, orange (sweet), mandarine, tangerine and sweet lime, are affected in addition to cashew, mango, bread-fruit and jak-fruit ; whilst in other countries apple, apricot, banana, fig, grape, guava, litchi, nectarine, peach, pear and pomegranate, have been recorded as other adult food-plants ; it is noteworthy that in South Africa grape-fruit does not appear to be attacked. Available information regarding fruit-piercing species and their biology is meagre compared with that of many other groups of economic insects, and it is considered desirable to place on record observations made in Sierra Leone.

Difficulties in the way of the study of these insects are the lack of knowledge regarding (*a*) larval food-plants ; (*b*) characters and habits of the larvae ; (*c*) the breeding areas and possible migratory habits of the larvae ; (*d*) the breeding areas and possible migratory habits of the adults of some species.

Unless otherwise stated this account applies to Njala, where there is a plot of budded citrus ; the trees were planted in 1925–1927 and mainly consist of Late Valentia and Washington Navel orange, and Marsh and Foster grape-fruit. The sweet lime, mandarine and tangerine are about ten years older.

Many species are involved, the more important belonging to the genera *Achaea*, *Anua*, *Hypocala*, *Othreis* and *Serrodes*, although *Cocytodes*, *Heliophisma*, *Pericyma*, and *Sphingomorpha* are collectively of importance ; other piercers which are not common belong to *Lacera*, *Lagoptera*, *Pseudotolna* and *Tolna*, while *Dermaleipa*, *Enmonodia* and *Parallelia* probably include species with the habit, and possibly also *Anomis*, *Cyligramma*, *Delta*, *Miniodes* and *Mocis*. In addition to these Noctuids, *Charaxes* spp. (NYMPHALIDAE) occasionally pierce soft fruits. A list of the species follows, indicating also the months in which they have been observed at fruit, and otherwise (including bred specimens) ; a list is also given of fruit piercers recorded in other countries ; a third list gives recorded larval food-plants.

Insect	Attacking citrus	Attacking other fruits	Observed but not seen attacking fruit
Achaea albicilia, Butl. ...	iv, vi	iv, v	
albifimbria, Wlk. ...			ii
boris, Geyer		v	iv, v
catella, Guen.... ...			
catocaloides, Guen. ...	iv, v, vi, vii	iii, iv, v, vi	ii, x, xii
dasybasis, Hmps. ...	iv, v, vi, viii	v	
ezea, Cram.	iv, v, vi, vii	ii, iv, v, vi	ii, viii, ix, x, xi
faber, Holl.	i, iii, iv, v, vi, vii	iii, iv, v, vi	viii, ix, x, xi
finita, Guen.	iv, v, vi	iv, v	x, xii
hieroglyphigera, Strand			
indicabilis, Wlk. ...	iv, v, vi		vii
lienardi, Boisd. ...	iv, v	iii, iv, v, vi	
mercatoria, F. ...	iv, v	iii, iv, v, vii	
mormoides, Wlk. ...	iv, v, vi, vii, xii	iii, iv, v, vi	i, ii, viii, x, xi
trapezoides, Guen. ...	v, vi	iv, v, vi	

[*Continued overleaf.*]

Insect.	Attacking citrus	Attacking other fruits	Observed but not seen attacking fruit
Anua david, Holl.	iii, v	v, vi, vii	iv.
dilecta, Wlk.		iii	iv, v
hampsoni, Holl.			xi
mejanesi, Guen.	v	iv, v, vi	
producta, Holl.	iv, v	iv, v, vi	iii, xi, bred.
rufescens, Hmps.			
selenaris, Guen.	iv, vi	iii, iv, v, vi	vii
tirhaca, Cram.		iii	
verecunda, Holl.			iii
Cocytodes maura, Holl.	iv, v, vi	iii, iv, v	i, vii, viii xi, xii
Heliophisma catocalina, Holl.	vi, vii	v, vi	i, viii
klugi, Boisd.	vii	iv, v	xi
croceipennis, Wlk.	iv, v, vi, vii	iv, v, vi, vii	viii
Hypocala deflorata, F.		iv	ii, iii, v, vi, x, xi, xii
rostrata, F.	iv, v, vi		i, ii, iii
subsatura, Guen.			i, iii, iv, v, vi
Lacera alope, Stoll.	iv		v
Lagoptera occidens, Hmps.	iv	iv, v	vi
Othreis divitiosa, Wlk.	iii, iv, v, vi, vii	iii, iv, v, vi	i, ii, viii, ix, x, xi, xii
fullonica, L.	i, iii, iv, v, vi, vii, xi	ii, iii, iv, v, vi	ix, x, xii
materna, L.	v		vi
Pericyma mendax, Wlk.	i, iv	iii, iv, v	x
Pseudotolna eximia, Holl.	v	iv	iii, vi
Serrodes partita, F.	i, iv, v, vi	iii, iv, v, vi, vii	
trispila, Mab.	iv, v, vi	iii, iv, v, vii	i, x, xii
Sphingomorpha aliena, Holl.			v
chlorea, Cram.	iv	iii, iv, v	i, x, xi
pudens, Holl.		v	
xanthoperus, Hmps.			xii
Tolna sypnoides, Butl.		v	
versicolor, Wlk.	iv, v	iv, v	

(Identifications by Imperial Institute of Entomology.)

Species recorded as fruit-piercers in other countries.

Species	Country
Achaea albicilia, Butl.	Southern Rhodesia
catella, Guen.	,, ,, , South Africa
catocaloides, Guen.	Uganda, Gold Coast
echo, Wlk.	S. Rhodesia
finita, Guen.	,,
janata, L.	Ceylon, India, Malay, Dutch E. Indies
lienardi, Boisd.	South Africa, Southern Rhodesia, Natal, Port. E. Africa, Gold Coast, Nigeria
mercatoria, F.	Malay
obvia, Hmps.	Gold Coast
sordida, Guen.	S. Rhodesia
trapezoides, Guen.	,,
violascens, Hmps.	,,

Species recorded as fruit-piercers in other countries—continued.

Species	Country.
Anua coronata, F.	India
tirhaca (*tirrhea*), Cram.	S. Rhodesia, Cyrenaica
Calpe emarginata, F.	S. Rhodesia
ophideroides, Guen.	India
provocans, Wlk.	S. Rhodesia
triobliqua, Saalm.	,,
capucina, Esp.	Japan
excavata, Butl.	,,
Egybolis vaillantina, Stoll.	Nyasaland
Hypocala subsatura, Guen.	India
Othreis divitiosa, Wlk.	S. Rhodesia
fullonica, L.	Malay, Indo-China, Dutch E. Indies, Fiji, Samoa, Australia, India, Rhodesia, Gold Coast
materna, L.	Rhodesia, India, Australia
serpentifera, Wlk.	Mexico
tyrannus, Guen.	Japan
Pericyma umbrina, Guen.	S. Rhodesia
Serrodes inara, Cram.	,,
partita, F.	South Africa
Sphingomorpha chlorea, Cram.	,, S. Rhodesia

Species	Larval food-plants	Country
Achaea catella, Guen.	*Bauhinia reticulata*, *Burkea africana*, Cabbage, *Callistemon* sp., *Eucalyptus* sp., *Euphorbia* sp., *Ricinus communis*, Rose	Southern Rhodesia
catocaloides, Guen.	*Alchornia cordifolia*, *A. hirtella*, *Byrsocarpus coccineus*, *Cnestis ferruginea*, *Cola nitida*, *Combretum comosum*, *Connarus africanus*, *Costus afer*, *Dichapetalum toxicarium*, *Dioscorea hirtiflora*, *Leptoderris* cf. *brachyptera*, *Macaranga huraefolia*, *Millettia Barteri*, *Napoleona Heudelotii*, *Ochthocosmus africanus*, *Phyllanthus discoideus*, *Sorindeia juglandifolia*, *Uvaria chamae*	Sierra Leone
	Coffee	Uganda
echo, Wlk.	*Eugenia cordata*, *Excoecaria reticulata*	Southern Rhodesia
ezea, Cram.	*Combretum comosum*, *Combretum mucronatum*, *Ochthocosmus africanus*	Sierra Leone
faber, Holl.	*C. comosum*, *C. mucronatum*	Sierra Leone
	Guttapercha	Dutch East Indies
finita, Guen.	*Ricinus communis*	Southern Rhodesia
	Rosa sp.	Mauritius
janata, L.	*Rosa* sp.	Australia, India, Malay
lienardi, Boisd.	*C. comosum*, *C. mucronatum*, *Napoleona Heudelotii*, *Ochthocosmus africanus*, *Phyllanthus discoideus*	Sierra Leone
	Acacia spp., *Royena pubescens*	South Africa

[*Continued overleaf.*

Species	Larval food-plants	Country
Achaea mercatoria, F.	Euphorbiaceae	Dutch East Indies
	Mimusops elengi	Malay
	Sapotaceae	India, Queensland
serva, F.	Guttapercha	Dutch East Indies
sordida, Wlk.	*Calpurnia laseogyne*	Southern Rhodesia
trapezoides, Guen.	*Acalypha* spp.	Mauritius
	Phyllanthus discoideus, Ochthocosmus africanus	Sierra Leone
violascens, Hmps.	*Faurea* sp., *Protea* sp.	Mauritius
Anua coronata, F.	*Combretum ovalifolium*	India
david, Holl.	*C. comosum*	Sierra Leone
mejanesi, Guen.	*C. comosum*	Sierra Leone
producta, Holl.	*C. comosum*	Sierra Leone
tirhaca, Cram.	*Combretum guienzii, Geranium* spp., *Leptospermum laevigatum, Psidium guajava, Rhus laevigata, R. villosa*	Southern Rhodesia
verecunda, Holl.	*Combretum comosum*	Sierra Leone
Calpe emarginata, F.	*Cissampelos torulosa*	S. Rhodesia
	Ophiocaulon gummifera, Stephania discolor	South Africa
provocans, Wlk.	*Cissampelos torulosa, Ophiocaulon gummifera*	Southern Rhodesia
Hypocala moorei, Butl.	*Diospyros montana*	Ceylon
rostrata, F.	Fagaceae	India
subsatura, Guen.	*Carapa moluccensis, Garcinia xanthochyma*	Malay
	Quercus incana	India
Maenas salaminia, Cram.	*Pericampylus incanus, Stephania* spp.	Queensland
Othreis divitiosa, Wlk.	*Dioscoreophyllum tenerum, Rhigiocarya racemifera*	Sierra Leone
fullonica, L.	*Cocculus hirsutus, C. indicus*	India
	Erythrina indica	Fiji, Samoa
	Excoecaria reticulata	South Africa
	Pericampylus incanus, Stephania spp.	Australia
	Tiliacora sp.	Java
	Dioscoreophyllum tenerum, Stephania Dinklagei, Synclisia ferruginea, Tiliacora sp. near *Dinklagei, Triclisia patens*	Sierra Leone

[*Continued on following page.*]

Species	Larval food-plants	Country
Othreis materna, L.	*Desmonema caffra*	Natal
	Rhigiocarya racemifera	Sierra Leone
	Tinospora cordifolia	India
tyrannus, Guen. ...	*Akebia quinata*	Japan
Pericyma umbrina, Guen. ...	*Acacia* sp.	Southern Rhodesia
Serrodes inara, Cram. ...	*Sapindus oblongifolius*	South Africa
partita, F.	*Deinbollia pinnata*	Sierra Leone
trispila, Mab. ...	*Lecaniodiscus cupanioides*	Sierra Leone
Sphingomorpha chlorea, Cram.	*Acacia hirtella, Diplorrhynchus mossambicensis*	Southern Rhodesia
	Sclerocerya caffra	South Africa

Most species have been observed to attack both citrus and other fruits. Of citrus, mandarine is preferred to orange, and orange to grape-fruit ; sweet lime is apparently preferred to any of these, but is seldom in fruit during the same period.

An interesting point is the relative importance (abundance) of different species from year to year ; in the following list they are given in descending order :—

1926—*H. rostrata*, F.

1928—*O. fullonica*, *A. lienardi*, *H. rostrata*.

1930—*A. catocaloides*, *A. lienardi*, *H. rostrata*, *O. fullonica*.

1931—*A. catocaloides*, *O. fullonica*.

1932—*A. catocaloides*, *O. fullonica*, *A. faber*, *Serrodes* spp.

1933—*O. fullonica*, *A. faber*, *A. mormoides*.

1934—*A. catocaloides*, *O. fullonica*, *A. faber*, *A. lienardi*, *A. mormoides*.

1935—*A. catocaloides*, *O. fullonica*, *A. ezea*, *faber* and *lienardi* about equal but totalling almost as many as *O. fullonica*.

1936—*O. fullonica*, *A. mormoides*, *A. faber*, *A. ezea* ; *A. catocaloides* was practically absent.

General Notes.

A. catocaloides is the most important species of *Achaea*, but the combined effect of the others is by no means negligible. Relative numbers vary from year to year, but after *catocaloides*, *faber* and *mormoides* are usually more numerous and are active over a longer period than the others ; *lienardi* is occasionally fairly numerous, as in 1928, 1930, 1934, and 1935, otherwise not common ; other species except *ezea* and *finita* are uncommon or rare.

Anua spp. ; not common except sometimes *mejanesi* and *selenaris*.

Cocytodes *~~i~~naura*, Holl. ; some years numerous. / m

Heliophisma spp. ; never common.

Hypocala spp. ; *rostrata* is the only important one, and may cause great damage, as in 1926.

Lacera alope, Stoll, *Pseudotolna eximia*, Holl., *Sphingomorpha* spp. and *Tolna versicolor*, Wlk., uncommon.

Serrodes spp. ; sometimes numerous, particularly during March and April.

Seasonal Occurrence.

Moths begin to appear in numbers about the end of March, when there is usually little citrus fruit. Cashews ripen in February and March, and mangoes in March and April, so that moths concentrate on these until citrus becomes suitable. Citrus is attractive from 4–5 weeks before maturity, but if nothing else is available it may be attacked some weeks earlier. Moths are most numerous during April and May, and practically all disappear by the middle of June ; probably climatic conditions form the determining factor (see Njala rainfall charts for 1932–1935 (fig. 1)). From July to February very few moths are to be found even in the presence of suitable fruit.

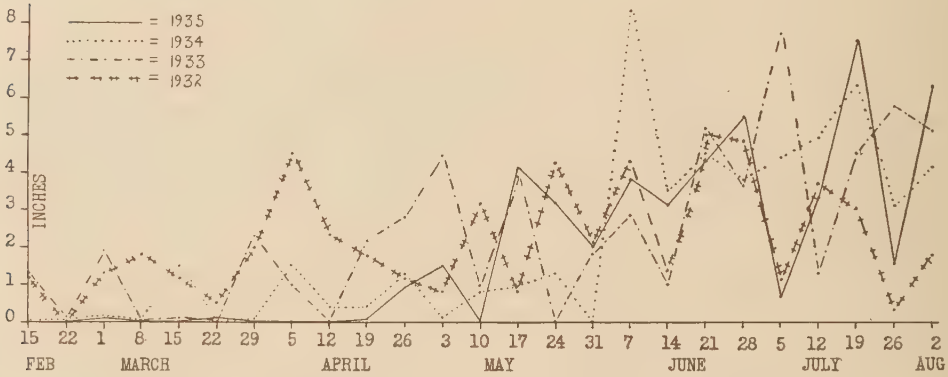

Fig. 1. Weekly rainfall, Njala, February to August, 1932–1935.

There are a number of indigenous fruits which would appear to be attractive, but they are not generally available during March to June; species of *Achaea*, *Anua*, *Heliophisma*, *Othreis*, *Pericyma* and *Serrodes* have been taken on *Anisophyllea laurina*.

Piercing and its Effects on Citrus.

Fruit is generally attacked when approaching ripeness, and puncture is followed by premature yellowing, the colouring commencing from the point of injury after four or five days ; as many as ten punctures have been seen on one fruit.

The majority of the punctures are made in the upper half of the fruit and nearer to the equator than to the button end; affected fruit usually falls, but it may remain on the tree for months ; in some cases the wound heals.

To determine the period elapsing between puncture and fall, artificial piercing by means of stainless steel pins was resorted to (one puncture per fruit), depths of puncture being made of $\frac{1}{2}$, $\frac{3}{4}$ and 1 inch, as this range covers the lengths of probocis of most species involved and it had been observed that the whole proboscis may be inserted. The first fall occurred 15 days after piercing (puncture 1 inch deep), the second after 21 days ($\frac{3}{4}$ inch deep), both oranges, and in the latter case there was a rotted area of 1 inch in diameter, visible externally around the hole.

The piercing was done on 28th July, 40 fruits being pierced and 40 marked as controls ; by the end of October the numbers of fallen fruits were :—

Fruit	Depths of puncture and number fallen			Controls
	1 in.	¾ in.	½ in.	
Orange	5 out of 5	4 out of 4	2 out of 6	1 out of 20
Grapefruit	5 ,, 7	5 ,, 10	4 ,, 8	1 ,, 20
Totals	10 ,, 12	9 ,, 14	6 ,, 14	2 ,, 40

During the period fruit-piercing moths were absent or negligible, but as climatic conditions are different from those obtaining when the moths are prevalent, it is possible that they have effect on the incidence and development of fungous spores, which may be reflected in the length of period before fall, and in the number of falls ; the period between punctures and fall is also somewhat dependent upon the degree of ripeness of the fruit, upon which presumably depends the rate of development of the organisms responsible. In the field, records indicate an average of about two weeks between puncture and fall during the moth season.

Pierced fruit was examined in collaboration with the Plant Pathologist, Mr. F. C. Deighton, who made cultures of the organisms found, and carried out inoculation trials in the laboratory. His findings may be summarised as follows—the main organisms which followed piercing were, on orange : varieties of *Fusarium moniliforme* ; on grapefruit : *Fusarium oxysporum*, *Fusarium theobromae*, varieties of *Fusarium moniliforme*, *Colletotrichum gloeosporioides*, *Oospora citri-aurantii*, and *Peroneutypella pusilla* (in one case only). A species of *Mycotorula* or *Candida*, often accompanied by *Saccharomycodes ludwigii* and bacteria, was commonly found, the yeasts being especially partial to sweet lime. Positive results were obtained by inoculations with the *Fusarium* spp., *Colletotrichum* and *Oospora*. (Identifications by Imperial Mycological Institute.)

These organisms must have been introduced by the proboscis of the insect, or gained entrance later, and to decide this a further series of puncturing was carried out using sterilised pins, those for the controls not being sterilised ; all the punctures

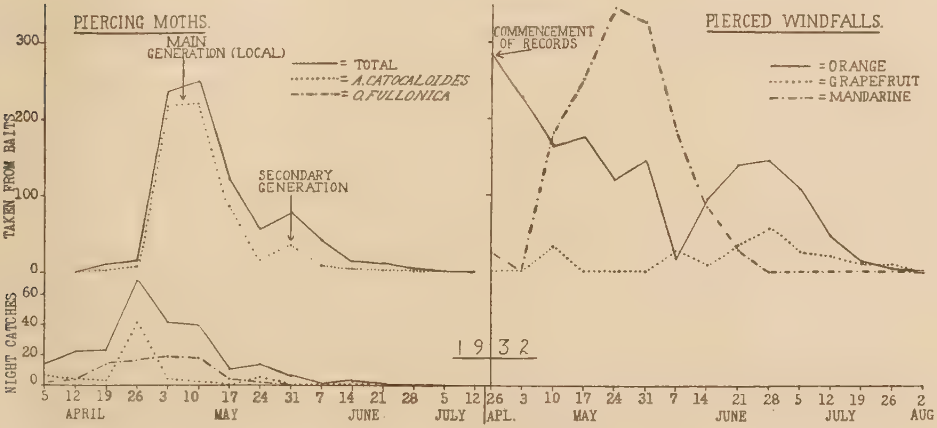

Fig. 2. Records for 1932.

were made to a depth of ¾ inch, in early November. There was no appreciable difference between the two, so that infection is not dependent upon introduction by the proboscis. It may be mentioned that the first fruit (orange, one of those for which a sterilised pin was used) fell a week after piercing, and 12 (6 of them controls) of the 24 treated fruits fell within 23 days; by the end of December, 10 of the 12 controls and 8 of the 12 others had fallen. The nearer the fruit is to maturity the more rapid the development of the fungi and the earlier the fall, while sweet orange was found to be more favourable for their development than grapefruit.

In most cases there was no external sign of rot on fruit-fall; internally, it was found that the fungus infection travelled from the puncture along the pithy material inside the rind and so to the button end (it may also travel towards the other end of the fruit but it appears that fall does not occur until the button end is affected), or between the juice cells or the sections of the fruit to the core and so to the button end.

Charts are given to show particulars of numbers of pierced fruits as indicated by pierced windfalls (from daily records), relative abundance of piercing moths as indicated by weekly night catches, and the numbers of moths taken from poisoned bait (from daily records), for the seasons 1932–35. In connexion with them the following details are given :—

1933—*Orange*: the main harvest was from April to July.
Grapefruit: main crop finished in February, next crop available for moths from April onwards.
Mandarine: main crop April–May.

1934—*Orange*: main crop finished by March, but second crop suitable from April.
Grapefruit: main crop finished in February, small second crop available from April.
Mandarine: first crop in May, second in December.

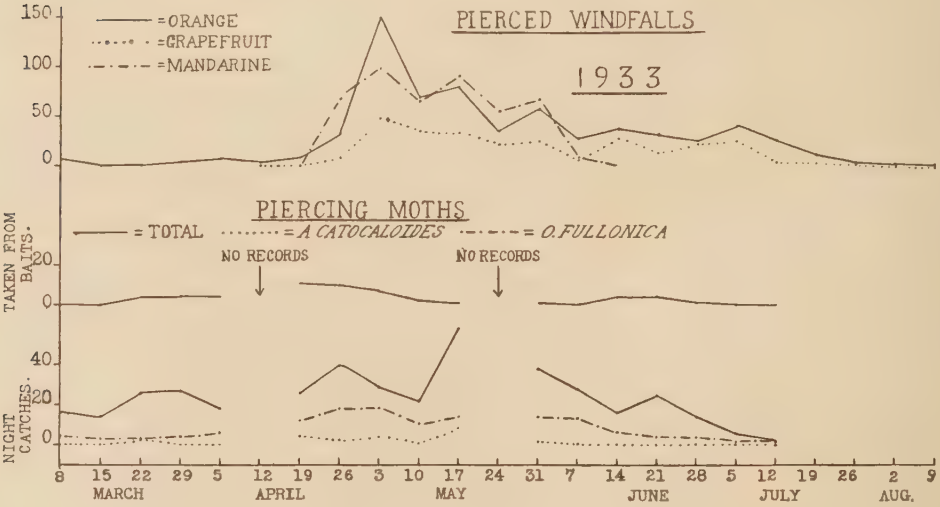

Fig. 3. Records for 1933.

It will be noted that variations in the numbers of moths caught by net are not reflected in the bait records until after a week or more; the main fruit fall due to effects of piercing occurs during May and June, the figures for this period (as percentages of total falls during the period April to July) for 1932–34 being 82, 80 and

100 respectively ; numbers of moths rapidly decrease as a result of the bait, but there appears to be a period, as indicated above, between arrival or emergence of the moths and their attraction to the bait, which accounts for the numbers of windfalls in spite of the baits ; increase in the number of tins (they were used at the rate of one tin per 25 trees) may result in complete control.

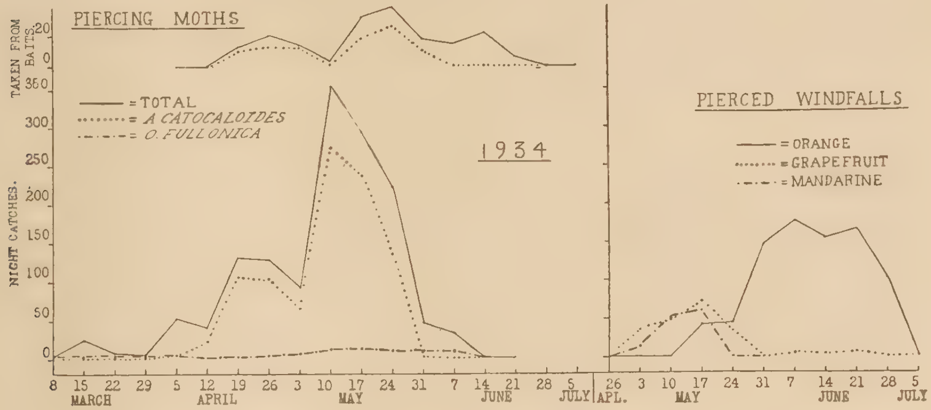

Fig. 4. Records for 1934.

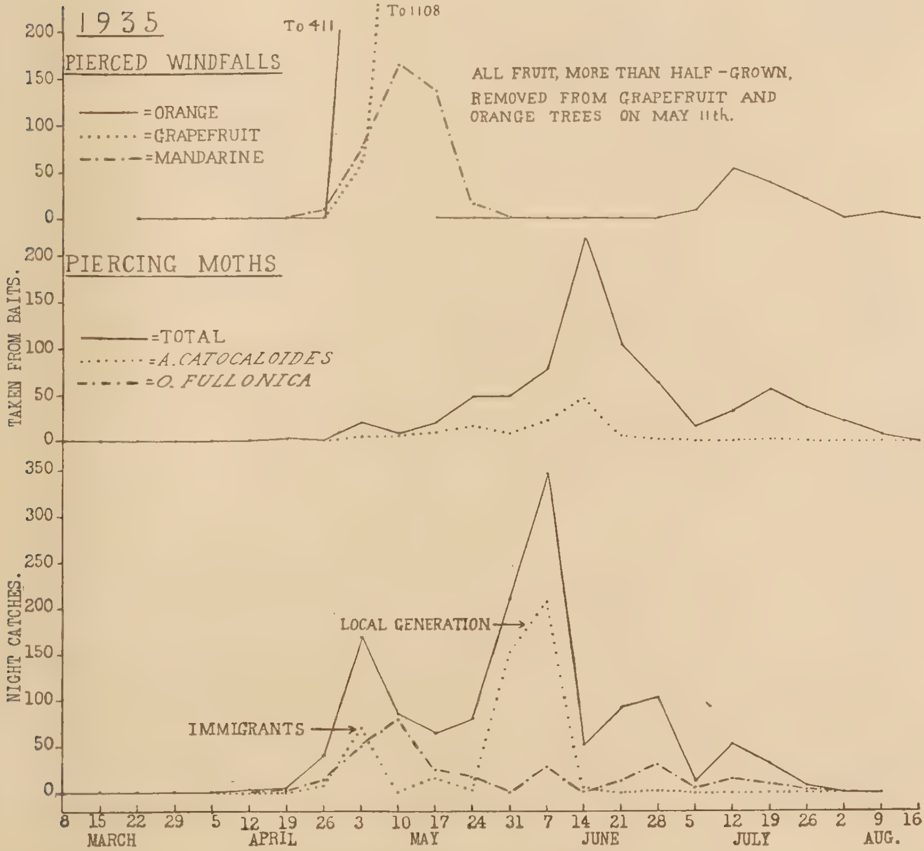

Fig. 5. Records for 1935

Variation in time of cropping has naturally an important bearing on the proportion of sound fruit obtained, as also has abundance of moths relative to amount of fruit available. Crop production during the months April to July inclusive compared with the total for the year was 63 per cent. for 1933 and 7 per cent. for 1934, the total crops for the two years being 20,590 and 64,320 respectively. In 1933, moths were comparatively few with much fruit available, while in 1934, moths were very numerous with only one-third the amount of available fruit, and the percentages of pierced fruits were 10 and 24 respectively of the April to July harvests (6.5 per cent. and 1.8 per cent. of the year's crops).

Genus OTHREIS.

Three species of *Othreis* have been noted in Sierra Leone, viz., *divitiosa*, Wlk., *fullonica*, L., and *materna*, L. ; all three species attack citrus, cashew and mango, but preference for soft fruits is not marked. As with *Achaea*, they are only active at night, taking shelter in the denser tree foliage during the day. Adults are in evidence from March to July, and are rarely seen at other times. Very humid conditions of climate, or microclimate, are apparently favourable to development, but heavy rains or relatively low humidity are not. In this probably lies the explanation of the occurrence on different food-plants during the year.

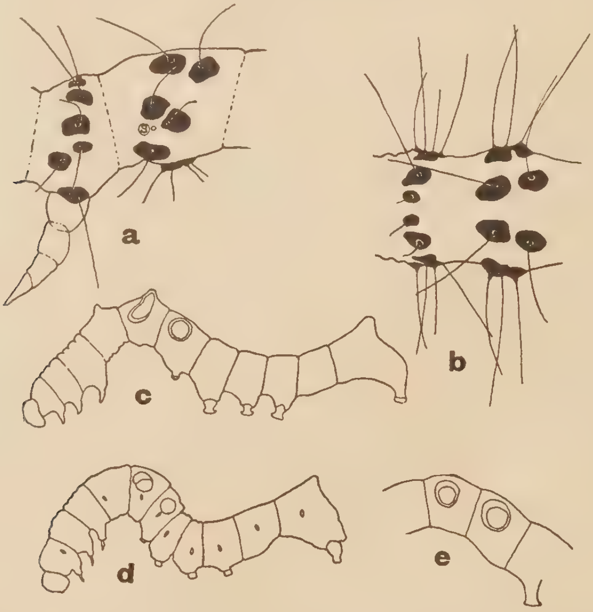

Fig. 6. **a–b**, *O. fullonica*, segments 3 and 4 of first stage larva :—**a**, from the side, **b**, from above ; *s*, spiracle ; **c**, *O. divitiosa*, last larval stage ; **d**, *O. fullonica*, last larval stage ; **e**, *O. matterna*, segments 5 and 6 ; note the absence of prolegs on segment 6.

Taking the case of *fullonica* : *Tiliacora* is a small-leafed slender twiner, and larvae are to be found on this only during the changes of season when the rain is not heavy or the humidity low ; in the periods between these they practically all occur on *Triclisia*, which is a large-leafed, semi-twiner, the leaves of the lower part of the plant being very dense and near the ground ; *Dioscoreophyllum* dies down in the dry season. During heavy morning mists, such as occur in November and December, when the humidity is very high with a great deal of condensed moisture present, larvae will leave the food-plant if it happens to be trailing near the ground for other more elevated species, and do not return until near the middle of the morning when much of the moisture has disappeared. If pupation occurs in dry surroundings, the adult is often unable to emerge successfully. In areas in which *Tiliacora* and *Triclisia* are common, but where the vegetation is now reduced to the orchard bush type, larvae are rare or absent.

Larvae of the 1st stage (fig. 6 *a–b*) are 5–8 mm. long, shiny and bright green with black tubercles each bearing a seta ; the 2nd stage is at first greenish grey, and it is during this stage that the two pairs of " eye-spots " on segments 5 and 6 develop (the posterior appearing before the anterior), also the dorsal hump on the 11th. There are five larval instars.

Larvae feed at any time, more especially between 5 p.m. and 10 a.m., their position being beneath or on the edges of the leaves, and generally drop when disturbed. The larval skin, except the head-capsule, is eaten after each of the four earlier moults, and pupation takes place in a slight silken cocoon within leaves folded or brought together by the larva.

All larval hosts so far found belong to the *Menispermaceae.*

Enemies appear to be rare, as only very few specimens of an Ichneumonid have been obtained from larvae of *divitiosa* and *fullonica*, and four parasites from one egg of the former. Bats are the main predators.

Othreis divitiosa, Wlk.

This species, although it breeds by the thousand, is seldom found to attack fruit or seen in the field ; it occurs during the same period as *fullonica*, but none has been seen on fruit, or in the field, between July and March.

Life-history and Habits.

The main larval food-plant is *Rhigiocarya racemifera*, a few being found also on *Dioscoreophyllum tenerum*, and both eggs and larvae are present to some extent during the whole year, although the main brood emerges between mid-November and mid-December.

Eggs are laid singly on the leaf under-surface, and as many as four have been seen on one leaf. The durations of the five larval stages are, commencing with the first—3, 2, 2–3, 3, 3–5 days, the total varying from 14 to 16 days; duration of the pupal stage varies from 14 to 18 days, with a mean of 16.

The pre-oviposition period (in December) is 6 days ; as was the case with *fullonica*, eggs failed to hatch ; only 40 were deposited during two days up to the death of the parent, but dissection revealed a further 250 in the ovary, making a total of 290.

The sexes are about equal in number.

Description of Stages.

Egg : the same as *fullonica*, but larger (diameter 1·27 mm.).

Larva (late 2nd, 3rd and 4th stages) : ventral part of eye-spots brick-red (in 2nd and 3rd stages), resembling those of *fullonica* of the same stages ; general colour dark grey-black, with a fair amount of white laterally over the 4th prolegs, a large white spot at either side of the posterior hump, a pair above the terminal pro-legs and a median dorsal spot (not present in the 5th stage) in front of the posterior hump.

The last larval stage (fig. 6 *c*) is 6–8 cm. long ; lateral diameter at 5th segment up to 1·0 cm. ; head brown ; general colour dark grey ; spiracles brownish ; posterior hump almost carmine with two pairs of lilac spots ; three pairs of sinuous pale stripes dorsally and a few lilac spots laterally ; small hump on 4th segment, a larger one on the 5th ; eye-spots large, mainly black, with 3–4 small lilac spots on anterior and 2-3 on posterior ; anterior spots pyriform, with anterior margins brick-red, almost meeting dorsally on the hump, posterior spots circular with a faint line of white on the ventral margins ; prolegs as in *fullonica*.

Othreis fullonica, L.

This, so far as has been observed, is the only important species ; it occurs in most years, but was absent in 1926. A few may be found early in the year attacking fruit, but they do not become at all numerous until March or April, and persist until June or early July (see charts).

Life-history and Habits.

Larvae have been found to feed on five species of *Menispermaceae—Dioscoreophyllum tenerum*, *Stephania Dinklagei*, *Synclisia ferruginea*, *Tiliacora* sp. near *Dinklagei*, and *Triclisia patens*, the two latter being the more important ; *Tiliacora* is the main food-plant during May, June, October and November, *Triclisia* in other months. Larvae are most numerous in October and November, much less so in May and June, and few are to be found at other times.

Eggs are laid singly on the underside of the leaves of the food-plant, and hatch in about 3 days.

The durations of the larval stages are as follows, starting with the first—3, 2, 2–3, 2–3, 4–9 days ; the pupal stage varies from 10 to 14 days, with a mean of 12·5 days.

The pre-oviposition period (only observed in one of the November moths) was 8 days ; during the next 4 days 155 eggs were laid, when the female died ; on dissection, a further 150 eggs were found in the ovary ; as no hatching occurred they were probably infertile.

Of the moths caught from March to June, 20–28 per cent. are female ; but of emergences during June and July, females are about 39 per cent., and in November-December more than 50 per cent.

Description of Stages.

Egg : spherical ; diameter 1·12 mm. ; pale green when first laid, darkening somewhat later.

Larva (fig. 6 *d*) : the normal general coloration of the larva is black or dark brown, but during May and June there is a preponderance of pale yellow to green ones, which when full-grown are on the average about 1 cm. longer than the others ; during July and August all are of the pale type ; towards the end of September the black type begins to appear, and during October and November green forms are rare ; the significance of this is not known. There are also occasional larvae of a greenish brown or pale brown colour, which approximate more to the yellow-green than to the black type.

Detailed description of the colouring arrangement with its pale blue, lilac and other markings would be impossible, but a general account of that of the two main types (last stage full-fed larvae) follows :—

(*a*) *Ordinary* (*dark*) *type* : length 5–6 cm. ; lateral diameter at 5th segment up to 0·8 cm. ; head brown ; general colour brown to black, velvety ; dark mid-dorsal line with paler areas alongside ; sides mottled with cream and lilac, with splashes of white or very pale yellow over the 4th and terminal prolegs, in the former case continued dorsally then posteriorly across the next segment ; white mottling on upper half of segments 7, 8 and 9 ; hump reddish-brown, with two pairs of small lilac spots dorsally, and a splash of white laterally ; spiracles brown, abdominal ones surrounded by a reddish-brown area bearing 2–3 lilac spots ; "eye-spots" nearly alike, with "pupil" of general body-colour bearing a lilac-coloured spot or crescent, the portion dorsal to the pupil being pale yellow and the lower part reddish orange (somewhat variable) ; anterior pair of prolegs much reduced but easily visible ; dorsal lilac spots on thorax.

(*b*) *Pale type* : length 5·5–7·5 cm. ; lateral diameter at 5th segment up to 1·0 cm. ; head brown ; general colour pale yellowish-green to olive-green ; abdominal segments pale bluish-pink dorsally ; mottling mainly white, a little pale blue ; hump green ; spiracles brown ; almost half (anterior-dorsal part) of anterior eye-spots white, continued as a narrow rim in lower portion, other part as general body-colour with a small pale blue spot ventrally just dorsal to a spiracle ; in the posterior eye-spots, the white portion is a narrow ring with a small pale yellow patch dorsally, the pupil of the general body-colour bearing a pale blue spot as in the anterior ; prolegs as in dark type.

(It will be noted that the head and spiracles of both the above are brown ; in *materna*, otherwise very similar, at least to the dark type, these are black.)

Othreis materna, L.

This species is very rarely seen in the field, at least about Njala (it appears to be more common to the north), and is of practically no importance ; they have been taken on citrus during May (until July further north, on mango).

Life-history and Habits.

Little is known of this species, as few larvae have been found and only on *Rhigiocarya racemifera* during May and June. Larvae refused to eat *Tiliacora.*

Durations of the stages are, larva 16–17 days, pupa 11–12 days. Of the five adults that emerged (in June) four were females.

Description of Stages.

Egg : not seen.

Larva (fig. 6 *e*) : last larval stage 6–7 cm. long ; head black (after 2nd stage) ; general colour black, mottling not very marked, mainly pale yellow with a little blue ; ring of blue spots on segments 2 and 3 ; spiracles black ; hump black with a few relatively large pale yellow to white markings on and behind it ; two pairs of lateral dark orange-coloured spots on segment 4, a pair on segments 2 and 3 (in younger larvae more conspicuous) ; mid-dorsal pale yellow patch on segments 4, 5 and 6 ; eye-spots almost identical in appearance, with black centre bearing a fine arc of blue ventrally, the ring being dark orange with a small portion pale yellow dorso-anteriorly ; legs and prolegs black ; first pair of prolegs completely absent.

Genus ACHAEA.

Moths of this genus appear to be more numerous as a rule than those of *Othreis*, and 15 species have been taken, only 6 of which are, however, of importance, *viz.*, *catocaloides*, *ezea*, *faber*, *finita*, *lienardi* and *mormoides* ; the first is most numerous and is in some years more serious than all other piercers combined. Preference is shown for soft fruits. Adults of any of the species are rarely seen between July and March.

Achaea catocaloides, Guen.

Evidence indicates that this species is migratory ; the adults generally appear at the end of March, and all specimens are much rubbed and tattered, as if they had travelled far.

Life-history and Habits.

The larval food-plants are very diverse, as will be seen from the list ; but the more important are *Ochthocosmus africanus* and *Phyllanthus discoideus.*

Immigrant moths deposit eggs in late March or early April ; they are laid singly on the upper or lower leaf surfaces, and hatch after 2–3 days. The larvae drop from the plant immediately upon disturbance, hanging suspended by a silken thread ; they are semi-gregarious and progress as loopers ; at rest, the head and thorax are raised and when interfered with by another one this portion is rapidly switched around apparently to strike the other, at the same time an attempt being made to bite, and the " fight " continues until one retires. After 18–20 days the larva spins a light cocoon within leaves either on or beneath the tree, and the adult emerges 7–8 days later. The pre-oviposition period of locally bred individuals is 4–5 days, so that a complete generation may only require 31 days ; 33 days was the minimum actually observed.

The adults normally feed at night ; during the day they rest in the shade of the denser trees and bushes, but mainly beneath fallen leaves and prostrate vegetation when present.

The main local generation emerges in early May, and there is a marked difference in sex proportion between these and the immigrant moths, the figures for 1934 being 55 per cent. and 11 per cent. females respectively as indicated by moths caught at night on fruit, while of those taken from the bait the ratios of females to males were 3 : 2 and 1 : 2 respectively.

Some of the earlier emerged moths deposit eggs, producing a second generation (this did not occur in 1935) at the end of May, but within the first week of June all have departed (this refers to Njala—8°·07″N. 12°·05″W).

In some years, as 1926, 1928 and 1933, the species is rare ; in the last year only 20 were caught during the season, of which one only was female, and no local breeding was recorded.

Regarding the question of migration, observations (kindly made by Mr. R. R. Glandville, Agricultural Officer) showed that *A. catocaloides* was numerous at a place 50 miles to the north about two weeks after their disappearance at Njala, and another week later none was to be seen at a town 100 miles to the north, although *A. finita*, Guen., *Othreis materna*, L., and *Sphingomorpha chlorea*, Cram., were present on mangoes there.

Since suitable fruit is available when the moths leave, the reason for their departure is difficult to surmise ; they usually arrive and depart on the same dates within a few days each year (in 1935 they did not appear until early May, which may have some connexion with the abnormally long and intense drought). There is also evidence of migration of this species in Uganda and the Belgian Congo (see References).

Description of Stages.

Egg : spherical ; diameter 0·92 mm. ; white when newly laid.

Larva (last stage) : length 5–6 cm. ; white mottled with black, giving a general effect of grey ; arrangement and amount of pigment vary somewhat, but there is a dark irregular area on each side of the abdominal segments dorsal to the spiracles, and a dorsal view gives the impression of two narrow white lines on each side with a black line between, running immediately dorsal to the dark areas mentioned ; ventral surface mainly white usually with dark areas on segments 3 and 4 just anterior to the prolegs ; a pair of dorsal yellow to tan processes, each bearing a terminal seta on segment 11 ; head of the same general colour as the body ; first pair of prolegs vestigial, 2nd pair partly and others fully developed ; spiracles dark brown. The prothorax bears a median ventral jugular gland with protrusible process.

Natural Enemies.

These are few, the only one noted being *Eumenes tinctor*, Christ, which was observed to fill its nests with the larvae ; all stages appear to be singularly free from parasites.

Control.

It does not appear likely that the commercial production of fruit can be so regulated by cultural practice as to avoid the fruit-piercing moth season (March to June inclusive) ; it is also evident that an attack on the larval stages of the moths is impossible, owing to the habit, habitat, and wide distribution of the food-plants, and we have therefore to deal with the adults.

Both light traps and poisoned baits were tried ; the former proved useless ; it was noted, however, that in some cases the moths (mainly *Achaea* spp.) were attracted by the hundred to the whitened ceilings of houses, although they did not go to the light itself, and it is possible that some arrangement of "flood-lighting" may be made use of.

With regard to poisoned baits, various mixtures were used with the object of finding a suitable substitute for arsenical compounds. The baits were put out in petrol tins, cut as described by Gunn ; the tins remained sound for 10 weeks or more.

Direct comparison of efficiency of the baits has not yet been found to be possible, as many moths must leave the bait after feeding and die elsewhere even in the case of arsenical preparations ; to encourage them to remain, some tins were cut about 6 in. deep and fitted with weatherproof wooden tops, the four sides being louvred to allow passage of the moths—they proved ineffective. Indication of relative attractiveness of baits is given, however, by the amount consumed, and further experiment will be made to ascertain effect on individual moths.

Different combinations of poison and attractant used were as follows :—

	grms.	honey (cc.) or sugar (grms.)	water (cc.)
Lead arsenate	3·0 –7·0	80–160	1,000
Sodium arsenite	0·75–1·8		
,, fluoride	2·0 –3·5		
,, fluosilicate ...	5·0 –7·0		

Additional materials included for possible increased attraction were :—cut ripe fruit (citrus, mango, pineapple) ; males and females of *A. catocaloides* and *O. fullonica* suspended within muslin bags ; palm wine, claret, vermouth, wine vinegar (it had been noted that wines are very attractive).

If the quantity of bait consumed be accepted as an indication of relative preference, the point emerges that there is no appreciable difference between baits containing the higher amounts of poison. The greatest quantities were taken in the cases of sodium fluoride 3·5 grams with honey 160 cc. ; lead arsenate 7·0 grams with honey 160 cc. ; and sodium fluosilicate 5 grams with Demerara sugar 160 grams. The following were next in order, there being little difference between them—sodium arsenite 1·8 grams, sodium arsenate 3·5 grams (each with 160 cc. honey) ; sodium arsenite 1·8 grams with Demerara sugar 160 grams ; lead arsenate 3 grams, white sugar 75 grams and 10 cc. claret ; sodium arsenite 0·75 grams, white sugar 75 grams and 10 cc. claret ; the amount of water was 1,200 cc. for each.

The amount of liquid found in the stomachs of gorged insects was about 0·25 cc. for *A. catocaloides* and 0·5 cc. for *O. fullonica*, but whether or not these are lethal doses of the baits has not yet been decided. Large or strong-flying moths like *Othreis* have ample time to leave the bait after gorging, which is the probable explanation of their absence from the bait tins.

Regarding the attractant, Demerara proved markedly superior to white or ordinary brown sugar, and somewhat so to honey ; the other inducements offered to the moths had no appreciable effect.

For comparison between lead arsenate at 7 grams and sodium arsenite at 1·8 grams strength, the numbers of *A. catocaloides* taken from one tin of each during a period of 12 days were 154 and 162 respectively ; since sodium arsenite is soluble, therefore not requiring to be periodically stirred, it is to be preferred. Up to the present, the formula found to give the best result with *Achaea*, as indicated by number found dead in the bait, is sodium arsenite 1·8 grams, Demerara sugar 160 grams and water 1,200 cc. ; the amount of sugar is about twice that in the South African formula (Gunn), and later work will show how much it can be reduced without losing efficiency.

In the laboratory, trial was made of the effect of a bait made up of sodium arsenite 1·0 gram, Demerara sugar 80 grams and water 1,200 cc. (almost identical with Gunn's formula) on *Achaea mormoides*, *Serrodes* sp., *Othreis divitiosa* and *O. fullonica* ; the two former were dead within a day of feeding. In the case of the two latter species, they were caged on the day of emergence with fruits (grapefruit, mandarine and orange) which were approaching maturity, in addition to bait, and it is probable that they do not feed until some time after emergence. One male and one female *divitiosa* died in two days, and although the fruit was not pierced they had fed on the bait ; the male was observed to feed on the bait about 46 hours after emergence, and four hours later it appeared to be ill, while after another four hours it had died. Two males and one female *fullonica* were dead two days after being caged, and had fed on the bait but not on the fruit ; in the case of another female, one of the fruits (a grapefruit) enclosed was fully ripe and after one day it bore 11 punctures, after two days 14, after three days 17, and the moth died on the fifth day, from which it would appear that fully ripe fruit is preferred to the bait, at least for a time. With a solution made up of sodium fluosilicate 0·8 gram, Demerara sugar 16 grams and water 120 cc., one male *fullonica* died within two days and the enclosed fruit was not attacked.

References.

JACK, R. W. (1916). Rhodesian citrus pests.—Rhodesian Agric. J., **13.**

COTTERELL, G. (1916). Report of Entomologist.—Gold Coast Agric. Dep. Rep.

RAMIREZ, R. (1920). A disease of oranges in Turicato, Michoacan.—Rev. Agric. San Jacinto, no. 7.

JACK, R. W. (1923). Insect pests of fruits other than citrus in Southern Rhodesia. —Rhodesian Dep. Agric., Bull. **450.**

HARGREAVES, H. (1922). Report of Entomologist.—Ann. Rep. Dep. Agric., Uganda.

SUSAINATHAN, P. (1923). Fruit-sucking moths of South India.—Rep. Proc. 5th Ent. Meeting, Pusa.

TRYON, H. (1924). Orange piercing moths (Fam. Ophiderinae).—Queensland Agric. J., **21.**

SUSAINATHAN, P. (1924). The fruit moth problem in the Northern Circars.—Agric. J. Ind. **19.**

CORBETT, G. H. & GATER, G. A. R. (1926). A preliminary list of food-plants of some Malayan insects.—F.M.S.S.S. Dep. Agric., Bull. no. **38.**

CLAUSEN, C. P. (1927). The Citrus insects of Japan.—Tech. Bull. U.S. Dep. Agric., no. 15.

FROGGATT, J. L. (1928). Notes on banana insect pests.—Queensland Agric. J., **29.**

GUNN, D. (1932). Fruit-piercing moths.—Farming in South Africa, 1929.

LEEFMANS, S. (1932). A fruit-piercing Noctuid (*Othreis fullonica*).—Trop. Natuur, **21.**

PITMAN, C. R. S. (1930). Observations on the excessive abundance and possible migration of a Catocaline moth in Uganda.—Proc. Ent. Soc. London, **5,** p. 64.

VINALL (Miss). (1931). The abundance of the Noctuid moth, *Achaea catocaloides*, Guen., in the Belgian Congo.—Proc. Ent. Soc. London, **5,** p. 75.

DIFFERENCES IN THE RESISTANCE OF THE INSTARS OF A PENTATOMID BUG TO PYRETHRUM POWDER.

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During the testing of finely ground pyrethrum flowers as an insecticide for the control of *Antestia lineaticollis*, Stål, in coffee trees, it was noticed that the various instars showed different percentage death rates under the same conditions. The experiment which is dealt with here was primarily designed to discover the minimum effective dose of powder per tree, and was carried out as follows.

A block of 1,700 coffee trees was divided into seventeen square plots each containing 100 trees. Nine of these plots were treated with pyrethrum powder at rates varying from about 1 gram to 5 grams per tree ; all the trees in the same plot receiving the same amount of powder. Two days later 36 trees from each of these plots, comprising all the trees from the centre of the plots (the two outer rows of each plot not being used in case migration of the *Antestia* should have taken place from the adjoining control plots) were heavily drenched with a strong kerosene extract of pyrethrum in order to bring down all the *Antestia* remaining on the trees ; these *Antestia* were collected separately for each tree, sorted into instars and recorded. This method of testing is described fully by Le Pelley (1934).

In each of the eight control plots five trees selected at random were drenched with the kerosene extract of pyrethrum and the *Antestia* obtained were recorded in the same way. It was found that the average number per tree of *Antestia* and of each instar present in each of these control plots, which were themselves evenly distributed through the whole block, was practically constant. It was therefore assumed that the numbers of *Antestia* and of each instar was the same for the plots treated with pyrethrum prior to this treatment, and the number of each instar found on the trees after treatment subtracted from this figure represented the number which had been killed by the pyrethrum powder.

In fig. 1 the number thus calculated to have been killed is represented as a percentage of the number assumed to have been present before the treatment. The averages of these percentages for each instar are joined by a broad line ; the percentages for each plot are joined by finer lines.

The percentage death rates of all stages in each of the nine experiments is shown by the dots at the right-hand side of the diagram.

The numbers of each stage calculated to have been present in each individual plot of 36 trees before treatment are as follows :—Adult 241 ; 5th instar 47 ; 4th instar 104 ; 3rd instar 169 ; 2nd instar 180 ; 1st instar 58. The mean percentage death rate of any instar is thus calculated from nine experiments, in each of which not less than 47 insects were used, and in most cases considerably more than this number. It will be seen from fig. 1 that the curves for the individual experiments are remarkably constant in shape.

Amongst the nymphal instars an increasingly high percentage death rate from the fifth to the first instar is obtained ; a higher percentage death rate of adults than fifth instars is, however, shown. The actual average percentage death rates was as follows :—Adult 52 per cent., 5th instar 17 per cent., 4th instar 54 per cent., 3rd instar 83 per cent., 2nd instar 92 per cent., 1st instar 94 per cent.

Since the adult only is capable of flight, it seemed possible that the anomalous result obtained for this instar might have been due to their having been driven out of the plots during the experiment, either as a result of the pyrethrum powder or because of the disturbance caused by the labourers engaged in the work. In another experiment of the same type, however, the *Antestia* from five trees chosen at random in each of the control plots were counted before the application of dust to the experimental plots, and those from ten other trees chosen at random in the control plots were counted at the same time as the treated plots were counted. If the adult *Antestia* had been driven out of the treated plots, the control plots should have shown an increase in the number of adults present ; actually they showed a slight decrease, as did all the other stages. Thus the adults were not driven from the treated plots to the control plots ; nor, since the decrease in the numbers of adults in the control plots was insufficient to account for the apparently large percentage death rate in the treated plots, were they driven out of the block altogether. The experiment referred to here, though it gave precisely the same result as the one under discussion, is not reproduced because in the former experiment some of the instars, particularly the first, were present in such small numbers that the result could not be considered dependable.

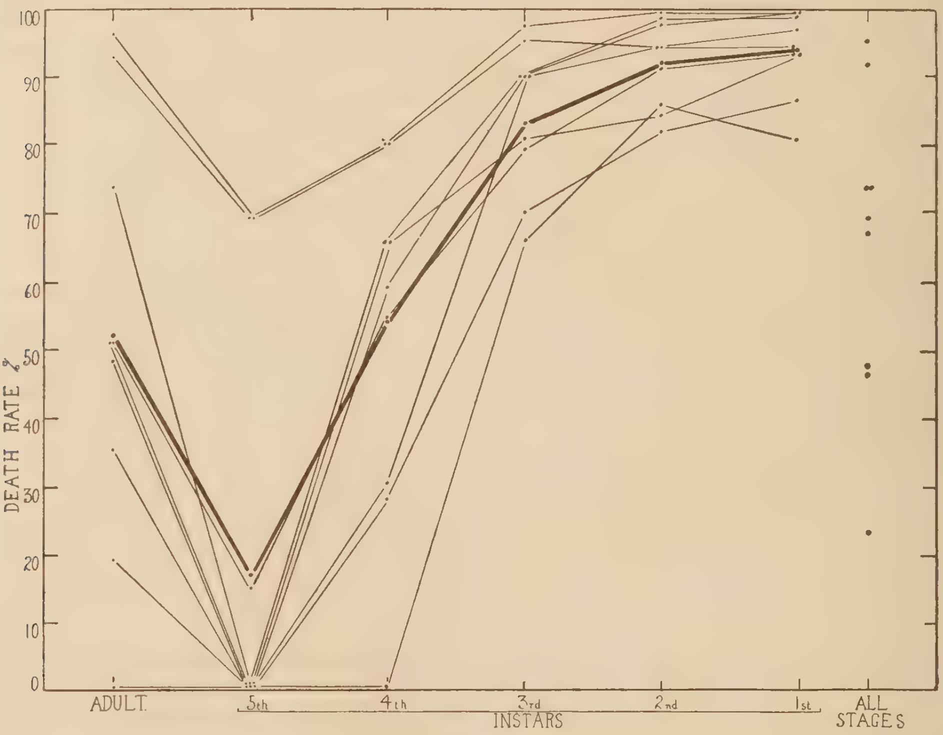

Fig. 1.

As a check on this result, *Antestia* in the adult, 5th and 4th instars were tested in the laboratory with pyrethrum powder. The insects used for these experiments were collected in the field, and owing to the difficulty of handling them the younger stages were not collected. The time taken for an insect to become moribund (*i.e.*, to be unable to regain its feet when it falls or is placed on its back) is taken as an indication of its resistance to the insecticide. The three instars required the following length of time to become moribund :—

Adult	468 ± 83 seconds.
5th instar	508 ± 154 ,,
4th instar	361 ± 79 ,,

Although these figures are not significant they provide a further indication that the higher percentage death rate amongst the adults in the first experiment is due to a lower resistance of this stage to pyrethrum than that of the fifth instar.

An interesting point which arises from a study of fig. 1 is that in a series of experiments, in which the percentage death rates of all stages varied from 23 to 96 according to the amount of pyrethrum powder applied, this variation was largely due to the variations in the death rates of the older stages. For instance, in the experiment resulting in only 23 per cent. of all stages being killed, the percentage death rates of the various stages were : Adult 0 per cent., 5th instar 0 per cent., 4th instar 0 per cent., 3rd instar 66 per cent., 2nd instar 86 per cent., 1st instar 81 per cent. (The difference between the average of these percentages and the average given for all stages is accounted for by the different numbers of each stage present). Throughout all nine experiments, the percentage death rates of the first and second instars varied only from 80 to 100 per cent., whilst those of the fifth instar varied from 0 to 96 per cent. The result of this might well be serious in practice ; the greatest check on increases of *Antestia* in the field is due to the high percentage parasitism of the eggs, chiefly by *Hadronotus antestiae*, Dodd, and *Microphanurus truncativentris*, Dodd. A light application of pyrethrum dust, sufficient to kill the majority of the two younger stages but to leave the majority of the older stages alive, will result, when these younger stages should have reached the adult stage, in a big diminution of the supply of eggs, and hence of the supply of parasites. The progeny of the older stages which escape death from the pyrethrum powder will thus start to lay eggs when there is a much depleted parasite population, and the foundations of an epidemic outbreak, such as is common from undetermined causes with *Antestia* in coffee, may be laid. Anderson (1919) has shown however that the length of the adult female life, during nearly the whole of which she lays eggs at regular intervals, is on the average longer than the average length of all the nymphal stages, so that the parasite population would not die out altogether even if all the nymphal stages were killed.

References.

Anderson, T. J. (1919). The Coffee Bug, *Antestia lineaticollis*.—Bull. Div. Ent., Dep. Agric., B.E. Africa.

LePelley, R. H. (1934). Pyrethrum-extract spraying for the control of *Antestia* on Coffee.—Bull. no. 8 of 1934, Dep. Agric., Kenya.

EXPERIMENTAL WORK WITH THE TSETSE-FLY, *GLOSSINA PALPALIS*, IN UGANDA.

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(Plate XVIII.)

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Introduction.

This is an account of laboratory experiments made with the tsetse *Glossina palpalis*. The results deal mainly with the effects of climatic conditions, temperature and humidity in particular, on the metabolism and life-cycle. Some work was also done on the activity and behaviour of the fly, but this is very incomplete, though it shows the importance of the problem and the need for further study.

The work was done during a visit of just over a year to East Africa, in 1935–36, as Wandsworth Scholar of the London School of Hygiene and Tropical Medicine. I spent most of the time at the Human Trypanosomiasis Institute, Entebbe, Uganda, and also visited tsetse areas in Kenya and Tanganyika. I am grateful to all those who helped to make my visit profitable. Among others, to the Directors of Medical Services of the East African territories, in particular the Hon. W. H. Kauntze of Uganda, and many members of their departments. To Mr. C. B. Symes, Medical Entomologist, Kenya, and to Mr. W. H. Potts, of the Department of Tsetse Research, Tanganyika. I am especially grateful to Dr. H. Lyndhurst Duke, Director of the Human Trypanosomiasis Institute, for many kindnesses. Considerable assistance was received from Mrs. Helen Mellanby, who was working on allied problems at

Entebbe. And mention must be made of the intelligent and conscientious help of my laboratory assistant, Omw. Bonaventure Semalwadde.

Material and Technique.

Pupae produced by wild tsetse were collected from the "fly beaches" in the neighbourhood of Entebbe, and the flies emerged in the laboratory. In this paper these pupae are referred to as "wild pupae." Flies were caught in hand nets in the field, and these are referred to as "wild flies." "Laboratory pupae" are pupae produced by female flies in captivity in the laboratory. Some of these were obtained from my own experiments, and Dr. Duke kindly allowed me to use pupae produced by flies used in his trypanosomiasis work.

Most of the experimental methods are described in the text, or, if similar apparatus has been used before, references are given to papers containing fuller accounts.

Analyses were made by the following method. The flies were anaesthetised with ether, and weighed on a torsion balance. They were then dried to constant weight at 100°C.—this appears to drive off very little except water. The amount of fat was estimated by dissolving and extracting it with ether; this also dissolves small quantities of certain allied substances, but gives a fairly accurate idea of the amount of fat that was present.

Live flies were weighed before and after meals inside a weighing bottle on a "chainomatic" balance. This was quick and accurate, and using a weighing bottle meant that it was unnecessary to clip the flies' wings.

Climatic Conditions and the Metabolism of the Adult Fly.

Survival of starvation.

Flies of different ages were starved to death under several conditions of temperature and humidity. In the first series of experiments they were placed inside celluloid cylinders 7½ cm. in diameter and 9 cm. tall, covered top and bottom with gauze and kept inside fruit jars (see Buxton & Mellanby 1934). The humidity was controlled by a layer of appropriate potash solution. Table I gives results obtained with unfed flies under 24 hours after emerging from wild pupae, and with similar flies kept a further 24 hours and fed on a chicken. Only individuals which fed well were used.

TABLE I.

Average Survival, in Days, of starved Glossina palpalis. *All 24°C. Examined once in 24 hours.*

	R.H.%	♂♂	♀♀
Unfed flies...	88	5·64 S.E. 0·13 92 flies	4·50 S.E. 0·14 56 flies
	65	5·19 S.E. 0·17 64 flies	3·96 S.E. 0·13 44 flies
	44	4·31 S.E. 0·29 26 flies	3·06 S.E. 0·19 31 flies
	19	3·46 S.E. 0·52 13 flies	2·45 S.E. 0·20 33 flies

TABLE I.—*continued.*

	R.H.%	♂♂	♀♀
Fed flies	88	8·29 S.E. 0·23 44 flies	6·42 S.E. 0·32 28 flies
	65	7·78 S.E. 0·31 36 flies	6·73 S.E. 0·20 37 flies
	44	5·88 S.E. 0·18 45 flies	5·29 S.E. 0·18 32 flies
	19	4·61 S.E. 0 09 49 flies	4·14 S.E. 0·13 22 flies

The following conclusions may be drawn from these figures :

(1) Under similar conditions, flies which have taken a blood meal survive longer than those which have not.

(2) Males survive better than females (most of the differences shown in the table are statistically significant).

(3) Fed flies survive equally well at 88 and 65 per cent. relative humidity. The unfed flies survive almost as well at 65 per cent. as at 88 per cent.—the difference is doubtfully significant. They all die more rapidly at the lower humidities.

The dead bodies of many of the starved flies were analysed to show how much " Ether Soluble Fat " remained. This is the principal reserve of the tsetse, which after each meal rapidly transforms the blood into " fat-body."

TABLE II.

Fat left in Bodies of 258 *Flies starved to Death at four different Humidities* (24°C.). *Averages in all Cases* (*Milligrams*).

R.H.% ...	88	65	44	19
Unfed ...	0·167	0·168	0·500	0·544
Fed ...	0·158	0·155	0·170	0·327

The quantities are small, but show that the flies die from starvation at 88 per cent. and 65 per cent. relative humidity containing only small traces of fat. At the lower humidities they die (from desiccation) before they have utilised all their reserves.

Experiments were also made at 20°C. and 30°C., and the results were what might be expected. The flies subjected to starvation only (at high humidities where desiccation is not the limiting factor) survived longer at 20°C. than at 24°C., and for a shorter period at 30°C. Under conditions of intense desiccation they died rapidly—even fed flies survived only 2·70 days at 19 per cent. R.H. and 30°C.

These starvation experiments all show that while very dry air is unfavourable to *Glossina palpalis*, moderately dry air (*i.e.* with a relative humidity of 65 per cent.) does not have any harmful desiccating effect. The " Optimum Humidity " at 24°C. stretches at least between 65 and 88 per cent. The mean humidity of the air in many areas considered to be too dry for *palpalis* is considerably higher than 65 per cent.

Glossina tachinoides and *submorsitans*, which occur in much drier regions than *palpalis*, are better able to resist moderate desiccation, though in drier air their survival is not very different (see Buxton & Lewis 1934).

In all the experiments described above celluloid cylinders were used. Further experiments were made to see whether different-sized containers affected the activity and survival. When flies were kept in smaller containers, such as tubes 7 × $2\frac{1}{2}$ cm. or 5 × 4 cm. (covered at the top with gauze), and also in others in which they were kept from flying at all by being pressed gently against the gauze by a cottonwool plug, the survival times did not differ appreciably. Large cages did affect the result. Flies were kept in a cage 1 × $1\frac{1}{2}$ × 2 metres, and the survival compared with that in 5 × 4 cm. tubes. These two experiments were done simultaneously, and the temperature and humidity were those of the room (22–26°C., 60–90 per cent. R. H.). The average times of survival are shown in Table III, and the results are all significantly different from each other.

TABLE III.

Average Survival in Days of newly emerged unfed Flies kept in a large Cage and in 5 × 4 cm. Tubes (3 per Tube).

Big cage	47 ♂♂ 53 ♀♀	4·05 days 3·09 days	S.E. 0·158 S.E. 0·138
Tubes	43 ♂♂ 60 ♀♀	4·58 days 3·65 days	S.E. 0·115 S.E. 0·104

Next, batches of flies were kept in the large cage and the tubes for 48 hours, after which they were killed and analysed. It will be seen that whereas the proportion of water and dry matter is almost the same in both lots of flies, those which were kept in the large cage used up more of their reserves. They appeared to be more active than those in the small tubes. The greater activity would cause a faster utilisation of reserves and the more frequent opening of the spiracles would accelerate evaporation and cause the metabolic water to be lost, for otherwise the more active flies would have had a higher proportion of water in their bodies.

TABLE IV.

Analysis of unfed Flies kept for 48 Hours in large Cage and 5 × 4 cm. Tubes. Averages in all Cases (Milligrams).

Big Cage	Live wt.	Dry wt.	Dry wt. as % of live wt.	Fat
23 ♂♂	18·24	5·44	29·8	0·74
25 ♀♀ .	18·68	5·52	29·5	0·48
Tubes				
27 ♂♂	18·82	5·66	30·1	0·85
21 ♀♀	19·52	5·76	29·5	0·71

The importance of activity was demonstrated in another way. New rubber washers sometimes give out a toxic emanation in moist air (Mellanby & Buxton 1935). One batch of washers when fairly new caused anaesthesia instead of death, and flies shut up with them appeared quite dead but soon recovered in fresh air. They survived a long period in this dormant state—at 24°C. and 88 per cent. R.H., 29 unfed females survived 6·74 days and 20 males survived 9·55 days (*cf.* Table I; the anaesthetised flies survived more than 50 per cent. longer than the others). Figures given in a later section (p. 627) show that young females were more active than young males. This explains why they used up their (initially larger) reserves so quickly and died so rapidly.

Some deaths occur in captivity with flies of all stages, and so starvation experiments with older flies were more difficult, for it was impossible to tell at the beginning if any individuals had reduced vitality. A number of flies were fed one day after emergence, and then again three days later. Their survivals (at 24°C.) are given in Table V.

TABLE V.

Mean Survival (Days) of Flies after two Meals (24°C.).

R.H. %	♂	♀
88	8·71 S.E. 0·51 17 flies	7·59 S.E. 0·46 12 flies
65	8·36 S.E. 0·28 22 flies	7·62 S.E. 0·56 13 flies
44	7·37 S.E. 0·21 19 flies	6·50 — 6 flies
19	5·80 — 5 flies	— — —

The females survived better than those which had had one meal only, but the apparent longer survival of the males is not significant. There is less difference in the survival of the sexes, perhaps because older females are less active than young (p. 627). These flies also showed increased resistance to desiccation—even as low a humidity as 44 per cent. was not very harmful to them.

Some experiments were done in which the actual weights of blood taken were measured. Female flies took considerably more on the average at their second meal, which helps to explain the results in Table V. The larger the meals taken the longer the flies survived on the whole, but there was considerable irregularity.

An attempt to breed flies under controlled conditions.

In preliminary experiments in which flies were kept in celluloid cylinders (see p. 612) inside fruit jars under standard conditions and offered food frequently, it appeared that feeding was very important. Dissections showed that practically every fly which died did so from starvation, for its gut was empty and it had hardly any reserves in its fat-body. The only exceptions were in dry air, where some reserves were found in desiccated flies, and in very moist air where individuals became stuck up with excrement. I tried therefore to make the opportunities for feeding as uniform and as favourable as possible.

The feeding was done thus: chickens were fastened to boards, and the cylinders were held gently but firmly against their sides by rubber loops, so that any fly which tried to feed through the gauze at the bottom of the cylinder could do so. This lessened the labour, and reduced the " human element." The flies were given 10 minutes to feed, removed, and the number which took blood counted; the unfed individuals were then given a further 5 minutes. As a rule about 80 per cent. fed in the whole 15 minutes.

A large number of experiments were started in which 10 females and 2 males were put into each cylinder. These were kept at four different humidities—88, 65, 44 and 19 per cent. These humidities were combined with three temperatures—20, 24 and 30°C. Those at the two lower temperatures were offered food every second day and those at 30°C. were offered food daily.

Some results are shown in fig. 1. It gives the percentage survival of flies at 24°C. and four humidities over 30 days. It will be seen that there is practically no difference between the results obtained at 88 and 65 per cent. relative humidities, which supports the conclusion arrived at in the "Starvation" experiments, that at 65 per cent. R.H. the flies are in no danger from desiccation. The survivals at the lower humidities were less. Once again desiccation was of importance.

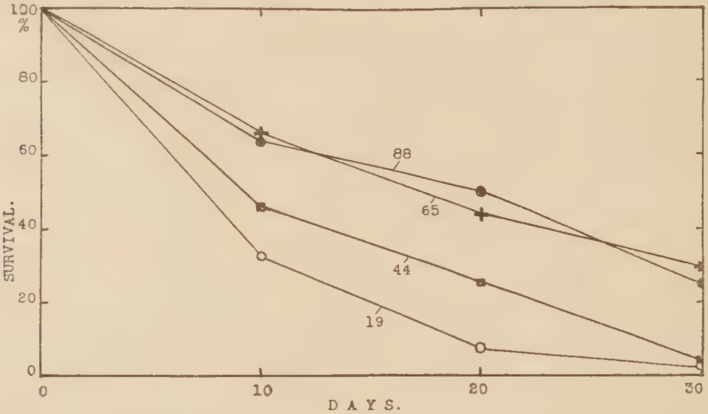

Fig. 1. Survival of *Glossina palpalis* at 24°C. and 4 humidities. Flies were offered food for 15 minutes every second day.

Under the conditions which have just been described humidity does not apparently affect the number of flies which feed. Figures obtained for flies which actually did feed in 15 minutes are as follows: at 88 per cent. R.H., 77·9 per cent. fed; at 65 per cent. R.H., 80·8 per cent. fed; at 44 per cent. R.H., 77·7 per cent. fed; at 19 per cent. R.H., 74·8 per cent. fed. There is no statistical significance in these differences; the figures are based on over 1,200 observations.* At first it appeared surprising that such a small proportion of the flies survived for 30 days when such a high proportion fed. The starvation experiments suggest that the survival times of fed flies should be sufficient to tide over the period if one meal were missed. These, however, are average figures, and some individuals die one or two days sooner. Missing one meal means 4 days starvation, during which a proportion of flies die, which is sufficient cumulatively to reduce the numbers as in fig. 1. Starvation alone killed nearly 75 per cent. of the flies at the higher humidities in 30 days, and the added factor of desiccation almost exterminated the culture in dry air.

Pupae were obtained at all humidities except 19 per cent. at 24°C. I do not propose to give the numbers here, for reasons given on page 622. At any rate, humidities as low as 44 per cent. had no harmful effects on breeding.

At 20°C. a rather higher proportion of the flies survived for 30 days at all the humidities, and again about 80 per cent. fed in 15 minutes. No pupae were produced, because none of the females were fertilised as the low temperature inactivated the males. In another experiment where the temperature accidentally rose to 22°C. on one or two occasions, due to a failure in the ice supply, copulation occurred at the higher temperatures and pupae were eventually produced. The flies did not survive at all well at 30°C., and were not eager to feed. No pupae were ever produced, although most of the females were fertilised, as the development of the ovaries becomes upset.

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* Flies kept in saturated air, and put on the chicken with a wet pad over the top of the cylinder to keep the air moist, fed equally readily.

Results of the kind which have just been described are not really satisfactory. It is not possible to keep the flies under controlled conditions and make feeding at all natural. In the field, a hungry fly can at any moment go and seek for food (even if it does not find it at once). In these experiments it is only possible to offer food for part of the time. It may be offered at just that moment when the fly does not desire to feed—it would have done so just earlier or later. Or a fly which would never have gone to *seek* for food may find it irresistible when put in contact. Experiments have shown that both difficulties are real ones. A fly which has refused to feed for an hour will bite readily ten minutes later. Had it not fed then it would have died of starvation within 24 hours. And flies can often be made to feed much more frequently than they would in the field.

Nash (1930) showed that tsetse-flies hunt mainly by sight, and when they have found their prey they are stimulated to bite by smell. In captivity, when food is offered, the sides of cages, etc., appear to offer the tactile stimulus necessary to make the smell of food sufficient to cause the fly to try to bite. When a cylinder is put on a chicken, flies try to bite the sides and top equally with the bottom (where they would find the chicken). They only find their food in these circumstances by chance, and a hungry fly may try to feed for a long time in an impossible place. After a time a fly, even if very hungry, "gets tired of trying to feed," perhaps like Pavlov's dogs, which went to sleep when the stimulus associated with food was repeatedly given and the food itself withheld. In nature a fly will seldom receive the stimulus to probe under such conditions.

The importance of the method of feeding was shown by another experiment. Flies were kept in the cylinders in the same way as before, and fed for 15 minutes. But after all the flies had been offered food for 15 minutes a few still remained unfed. If any of these were thin and unlikely to be able to resist starvation they were removed and special efforts made to feed them. This was not always easy, for very thin flies often refused food for a long time, but by persistent trying it was possible to make most of them take blood. As a result, out of 60 flies kept at 24°C. and 44 per cent. R.H., 48 (*i.e.*, 80 per cent.) survived for 30 days, and no further deaths had occurred up to the 37th day, when the experiment was stopped. In the earlier experiments only 3 per cent. of the flies survived for 30 days under these conditions (see fig. 1). It appears that by really careful feeding it is possible to keep *palpalis* alive under very dry conditions, and they even breed well. Great care must be taken to feed females which have just larviposited, as they appear particularly susceptible to desiccation.

When it appeared that such enormously different results could be obtained in these experiments, which lasted over a period of weeks, by slight changes in the procedure for feeding, I decided that more significant results could be obtained by using a different technique, and by making shorter experiments, each covering one stage only of the flies' development.

Feeding and humidity.

Humidity does not appear to affect the readiness with which flies feed, and the following experiments were made to see whether it affected the amount of blood taken.

In my first experiments flies which were known to have emerged for less than a day were put for 24 hours at different humidities. They were weighed separately, allowed to gorge on a chicken and weighed again at once (together with any small drop of excretion they might produce). Some results are given in Table VI.

TABLE VI.

Weight of Blood (Milligrams) taken by Glossina palpalis, *between* 24 and 48 *Hours old, after* 24 *Hours at different Humidities* (24°C.). *First Meal.*

R.H. %	♂	♀	♂ and ♀ together
88	23·45 S.E. 2·15 17 flies	30·86 S.E. 2·54 15 flies	26·94 S.E. 1·71 32 flies
65	25·95 S.E. 1·23 32 flies	26·90 S.E. 1·86 25 flies	26·39 S.E. 1·06 57 flies
44	27·30 S.E. 1·78 19 flies	25·35 S.E. 1·63 11 flies	26·93 S.E. 1·25 30 flies
19	22·74 S.E. 1·26 23 flies	25·13 S.E. 2·51 8 flies	23·35 S.E. 1·15 31 flies
Totals	24·95 S.E. 0·78 91 flies	27·42 S.E. 1·18 59 flies	25·92 S.E. 0·67 150 flies

None of the average figures is significantly different from the others, so we may conclude that exposure for 24 hours to different humidities (which is sufficient to cause the water to dry matter ratio to be altered, see p. 619) does not affect the amount of blood taken. There is little difference in the amounts of blood taken by the two sexes, for though the average amount taken by the females is higher, it is not significantly higher.

The same flies were kept for a further 3 days at the different humidities, and then offered food in a similar way. The results for this second meal are shown in Table VII.

TABLE VII.

Weight of Blood taken three Days after the Meal shown in Table VI. Same Conditions. Second Meal.

R.H. %	♂	♀	♂ and ♀ together
88	28·83 S.E. 1·86 17 flies	33·86 S.E. 3·12 15 flies	31·12 S.E. 1·93 32 flies
65	26·50 S.E. 2·11 22 flies	34·19 S.E. 1·90 16 flies	29·74 S.E. 1·639 38 flies
44	33·70 S.E. 1·45 13 flies	32·83 S.E. 3·39 6 flies	33·42 S.E. 1·41 19 flies
19	27·55 S.E. 2·50 9 flies	41·67 S.E. 5·37 3 flies	31·08 S.E. 3·01 12 flies
Totals	28·84 S.E. 1·16 62 flies	34·47 S.E. 1·57 40 flies	31·05 S.E. 0·97 102 flies

Again there is no statistically significant difference between the meals taken after exposure to the different humidities ; the average meal taken by the males is slightly larger than before (the difference is significant), and the females take considerably more blood. This can be correlated with the longer survival from starvation of female flies after taking two meals (see p. 615).

A number of other factors affect the size of the meal which the flies take. Flies which had emerged for less than 6 hours refused to feed, and any under 9 hours which did so took only a few milligrams of blood. After 12 hours they were able to take as large a first meal as they ever did, although a smaller proportion of the total flies fed readily at this age than when they were between 24 and 48 hours old.

When food is offered frequently, some individuals will take several small meals in the course of 24 hours. Other flies were persuaded to feed every day and the average size of all their meals (excluding the first) was only 15·42 mg. (36 meals, S.E. 1·53) or about half the normal size. Both sexes appeared to take equally small meals under these conditions. Buxton & Lewis (1934) found that in very moist air *G. tachinoides* fed less readily than in drier air, but took somewhat larger meals ; I presume that they took larger meals *because* they fed less often.

Older females took even larger meals than at the second feed. On one day seven females, all of which were in early stages of pregnancy and none of which had fed for at least 48 hours, took on the average 57·0 mg. Meals up to 80 mg. were quite common in similar cases, but it would be misleading to give an average figure for every meal taken by old females, as sometimes individuals (presumably not properly hungry) took only 2 or 3 milligrams. One female, which behaved in what appeared to be a " natural " manner and which produced a pupa weighing 37 mg. (fully as big as any found in the field), took three meals only during the whole period of gestation, and those meals averaged 60·3 mg. This fly could have obtained blood every day, and some females which produced smaller pupae took up to eight very small meals during gestation.

Older males never took such large meals. The average amount of blood taken by a number during one day was never found to vary very much from that taken at the first or second meal. The largest weight of blood taken by a male (out of hundreds of feeds) was 48 mg., and only about 10 per cent. ever took more than 35 mg. I was not able to weigh the amount of blood taken by wild males biting naturally but, after observing many feeding, I should estimate that they usually take between 30 and 50 mg. They have not the capacity of the females, but individuals which were not disturbed while feeding always took large meals (*i.e.*, over 30 mg.). It is unlikely that they are frequently disturbed after taking a small meal, for though the tsetse may take several minutes to start feeding, most of the blood is taken in very quickly. The unnaturally small meals often taken by males in captivity probably accounts for their developing smaller fat-bodies than wild flies. This point is discussed below (p. 620).

Metabolism and humidity.

1. *The unfed fly.*—The mean composition of flies which have emerged from wild pupae for less than 24 hours is as shown in Table VIII. At this stage the females are larger and heavier, and have significantly larger reserves of fat. The proportion of dry matter is almost identical in the two sexes.

Flies which had emerged for less than 24 hours were exposed to different humidities for 24 hours and analysed afterwards. Table IX shows some of the results obtained. It appears that at the lower humidities they lost most water, but that the same amount of the reserves was utilised in each case. There was no increase in the rate of metabolism in dry air to compensate for the water lost by evaporation.

Similar flies were exposed for 48 hours. Many deaths occurred in the lower humidities (from desiccation), but analyses of the survivors supported the conclusions arrived at from the shorter experiments.

TABLE VIII.

Analysis of Flies which have emerged from wild Pupae for less than 24 *hours.*

Number	Live wt. mgs.	Dry wt. mgs.	Dry wt. as % live wt.	Fat mgs.
65 ♂♂	21·93 S.E. 0·22	6·67 S.E. 0·08	30·41	1·46 S.E. 0·01
56 ♀♀	23·76 S.E. 0·15	7·39 S.E. 0·07	30·72	1·68 S.E. 0·01

TABLE IX.

Analysis of unfed Glossina palpalis *after* 24 *Hours' Exposure to three Humidities* (24°C.). *Males and Females together.*

R.H. %	Live wt. Mgs.	Dry wt. Mgs.	Dry wt. as % live wt.	Fat	Number
88	21·93 S.E. 0·73	6·656 S.E. 0·20	30·47	1·097 S.E. 0·08	15
65	21·49 S.E. 0·65	6·76 S.E. 0·73	31·43	1·094 S.E. 0·06	12
19	19·517 S.E. 0·43	6·55 S.E. 0·54	33·54	1·114 S.E. 0·12	12

2. *The fed fly.*—Jackson (1933) has described what he calls the " hunger cycle " in male tsetses. The hungry fly has an empty gut and a reduced fat-body. It feeds, and during the day or two after the meal the blood is digested and the fat-body increases to a maximum. Then the fat-body decreases once more and then the fly becomes hungry.

Laboratory flies which had taken large meals were dissected and analysed at daily intervals after feeding. Figure 2 is based on the results of some of the analyses, using flies kept at 24° C.and 65 per cent. RH. It shows that hungry flies contain very little fat. The blood taken at the meal does not add directly to the fat content of the fly, but within two days a large quantity is synthesised, evidently from the protein of the blood. The decrease of gross dry matter in the first two days after a meal is mainly due to excretion, but later the curve for " dry matter " runs parallel with that for " fat," which shows that it is mainly fat that is being metabolised.

Dissections showed that most of the blood had been digested within 2 days, and that the fat-body reached its maximum development in 2–3 days. With *palpalis* it is only possible to obtain figures like those shown in fig. 2 by using flies which have not fed for 5 days and selecting individuals which take large meals. If a random selection is made from a culture and individuals which take small meals are included, the average figures are misleading. A fly which takes a small meal will form only a small fat-body, which will be decreasing before that of another individual which took a large meal has reached its maximum. Reasons have already been given for assuming that such a state of affairs is unnatural. Then newly-caught wild flies do not behave naturally, as they are abnormally active, and this must upset their metabolism also. Jackson (1933) states that with *Glossina morsitans* the hunger cycle is not normal in captivity, and I should attribute the abnormality to the same causes which affect *palpalis*.

It was found difficult to obtain large numbers of flies as uniform as those which gave the results shown in fig. 2, and so the effect of humidity on the hunger cycle was investigated by using males from laboratory cultures, which definitely took a blood meal, but which had not necessarily starved for 5 days or taken a really large meal. These fed flies were subjected to several humidities for varying lengths of time, and then analysed to see how the humidity has affected the metabolism.

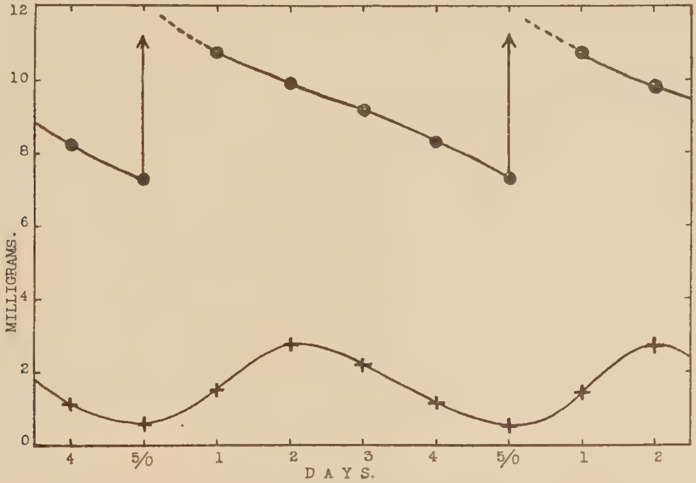

Fig. 2. The "Hunger Cycle" of *Glossina palpalis*. Flies fed on day 0. The upper line represents total dry matter, and the lower ether soluble fat.

TABLE X.

(a) *Analysis of Males fed once and exposed for three Days to four different Humidities, then killed and analysed* (24°C.).

R.H. %	Live wt. Mgs.	Dry wt. Mgs.	Dry wt. as % live wt.	Fat	Number
88	23·19	7·12	30·71 S.E. 0·18	0·938 S.E. 0·06	16
65	24·204	7·60	31·40 S.E. 0·35	1·07 S.E. 0·12	17
44	22·11	7·46	33·74 S.E. 0·33	1·004 S.E. 0·10	16
19	21·66	7·82	36·08	0·921	8

(b) *Males* 14 *Days old starved two Days at two Humidities after final Meal* (24°C.).

65	28·75 S.E. 0·66	9·18 S.E. 0·25	31·90	1·30 S.E. 0·148	18
19	26·24 S.E. 0·67	9·04 S.E. 0·37	34·42	1·28 S.E. 0·132	21

Table X gives results obtained with young flies which had taken only one meal analysed three days after feeding, and also with older flies (all males) exposed to two different humidities for two days. Evidently they all lose water more rapidly in dry air than in moist, but the reserves are consumed at the same rate in every humidity. These results were obtained by using individual flies, and the same conclusions were reached with parallel experiments in which batches were analysed after similar exposures.

The upper temperature limit.

The apparatus used to find the highest temperature which flies could survive was the same as that used by Buxton & Lewis (1934), and described in detail by K. Mellanby (1932). Flies were exposed to high temperatures, in air whose relative humidity was controlled for periods of one and of three hours. Young flies all survived as well as did healthy old flies ; but results with old flies were irregular, for weakened individuals died easily. The flies were removed from the apparatus after the experiment, and notes were made showing whether they were dead, feeble or active. None which appeared to be dead recovered, but many that were feeble died within 24 hours. Those still active at the end of the experiment survived as well as did ordinary ones which had never been exposed.

The flies survived for one hour at 40·2°C. at all humidities ; 43·0°C. was fatal in dry or moist air. At intermediate temperatures, moist air was almost invariably fatal, but a number of the flies survived in dry air. Weighing individuals before and after the exposure showed that they lost about 1 mg. of water in air with a relative humidity of 19 per cent., and only a one-tenth of a milligram when the humidity was 88 per cent. The surface area of the tsetse is such that if one milligram of water is evaporated in an hour, we should expect the internal temperature to be about one degree less than that of the air. (For detailed calculations on this subject see K. Mellanby, 1932.) This explains why they survive better in dry air.

In the three hours' experiments, 40°C. was fatal and 38°C. harmless at all humidities. No flies could cool themselves sufficiently by evaporation to survive for three hours at a higher temperature in dry air than in moist. As they died more rapidly in dry than in moist air in the starvation experiments, it is probable that had an experiment of this type lasting longer than three hours been made, the flies would have died more rapidly in dry than in moist air.

These results are almost identical with those found by Buxton & Lewis (1934) with *G. tachinoides* and *submorsitans*. These species may sometimes survive during the hottest part of the day by cooling themselves by evaporating water. This cannot apply to *palpalis*, which lives in places where the maximum temperature is far below the thermal death point.*

Sexual Physiology.

Fertilisation.

The breeding experiments described above were unsatisfactory because I almost always obtained insufficient numbers of pupae to maintain the population. Most laboratory workers have had the same result, and the experiments described below indicate that this is because they have over-estimated the potency of the male flies. Dissections have shown that unless there are many more males than females in a cage some females remain virgin for several weeks.

Although it has been denied by previous workers (Minchin, 1905), it is quite easy to see the sperm in a fertilised female by dissecting out the spermatheca and examining it by transparency under the microscope. Plate XVIII is a microphotograph† showing the difference between the spermatheca of a fertilised and an unfertilised female. Every female dissected, which was known to have copulated, or, if copulation had not been observed, had produced a larva, showed sperm as in Plate XVIII *b*. Those females from mixed cultures of males and females which did not produce larvae had empty spermathecae except in the case of a very few which had abnormal ovaries. It is possible by this method to tell whether wild females have been fertilised. One fertilisation has been shown by previous workers (Buxton & Lewis, 1934) to be sufficient to allow the female to produce larvae over a period of 10 weeks. Dissections of females which have been fertilised once and then had produced several larvae gave no indication that the sperm introduced at one pairing ever becomes exhausted.*

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* See p. 630.

† I am greatly indebted to Dr. H. B. Newham for making these microphotographs.

The process of copulation was investigated by using males and females which had remained virgin until they were 7 to 10 days old. If several of each sex were put into a cage the males at once pursued the females. The females appeared to vary greatly in their attractiveness, for several males would often rush at one female and all attempt to pair until one succeeded. The unsuccessful males would then pursue the next most attractive female, and some females were never molested. Even very attractive females often exhibited reluctance to pair, and prevented copulation by closing their wings and bending the tips of their abdomens downwards. It appears to be impossible for a male to pair with a really reluctant female.

Copulation lasts for from half an hour to two hours in the tsetse. Sometimes the flies appeared to have paired, but separated in a few minutes ; none of the females were fertilised. The sperm appears to be passed rapidly just before the flies separate voluntarily, for any which were forcibly pulled apart had empty spermathecae, even if others which started at the same time had already separated. The sperm enters the spermathecae at the time of pairing.

Flies will copulate a few hours after feeding, as soon as they have excreted sufficiently to make it mechanically possible.

Buxton & Lewis (1934) showed that *Glossina tachinoides* is not able to breed if the males and females are only kept together for 24 hours after emerging, but within 4 days some males are potent and females can be fertilised. I put young males and females of *palpalis* together in cylinders, offered them food every second day, and dissected the females 3, 4, 5, 6 and 7 days after emergence. No females were fertilised before the fifth day, whereas most were fertilised by the sixth. Next an experiment was made to see which sex was responsible for the delay. Males from 1 to 7 days old were put with females all of 8 days old. No males under 5 days old fertilised any females, but those 6 days and older were fully potent. Virgin males six weeks old were still fully potent. When males all 8 days old were placed with females from 1 to 7 days old in the first experiment, most of the females over 2 days old were fertilised, but those younger were not. A further experiment showed that some females under 24 hours old, and which have not even taken a meal, can be fertilised and eventually produce larvae. However, these young females do not appear to be very attractive, though they may be willing to copulate. To find at what age the female is most attractive, females of known age were placed with twice their number of potent males in a small cage. Dissection after 24 hours showed that among females aged 1–4 days, only between 20 and 40 per cent. were fertilised. In flies of 5 to 8 days old, an average of 75–90 per cent. was reached. Females older than 8 days become less attractive again. Wild males were found to fertilise almost exactly the same proportion of females as did laboratory ones, most males being able to fertilise at least two females within 24 hours.

The presence of a large excess of males has no harmful effect on the females, nor does it cause abortion. In one experiment 3 females were enclosed with 21 males. All the females were fertilised and produced pupae (there were actually no abortions at all in this experiment). Pregnant females do not appear to be attractive and so are not molested very much.* In the laboratory, the highest number of pupae was obtained in cultures containing about twice as many males as females. If these flies were fed carefully it was quite easy to obtain a number of pupae considerably larger than that of the flies present at the start of the experiment. Laboratory pupae were often undersized, but this was due to nutritional factors described elsewhere.

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* I have since found the spermathecae full of living sperm in a female 200 days fertilisation. Many pupae and abortions had been produced.

It at first appears paradoxical that, whereas every wild female over a week old which was dissected proved to have been fertilised, in the laboratory female flies in the same cage as males remained virgin for many weeks. But it was shown that females are most attractive at about a week old, and older ones are less attractive. Also the males do not lose potency with age. Now in the field the " fly-round " figures show that males of all ages, and young females, are very active, while older females are seen only when really hungry (see Jackson, 1933). Thus a condition is produced similar to that in the experiments in which the highest proportions of fertilisations was obtained where there are a small number of females at the most attractive stage and a great excess of males. In the laboratory when the males are in the minority a few very attractive females monopolise their attentions during the early stages, and apparently these same females are still more attractive (or less unattractive) than the others as they become older.

Humidity and fertilisation.

Experiments were made to see whether humidity affected the proportion of flies which was fertilised. First, equal numbers of males and females, all virgin and all 7 days old, were put into cylinders at 44 and 88 per cent. relative humidity and dissected at the end of 48 hours. Examination of the spermathecae showed that at 88 per cent. R.H. 50·0 per cent. were fertilised, and at 44 per cent. R.H., 45 per cent. (20 females in each case).

Secondly, equal numbers of males and females were kept together for the first eight days of their lives, under different conditions of humidity, and then dissected ; 7 out of 18 females kept at 44 per cent., and 5 out of 10 at 88 per cent. relative humidity, were fertilised.

These results indicate that fertilisation occurs equally readily in dry or moist air, and does not help to explain the conclusion of many field workers that tsetse appear to breed most freely in the dry season.† Breeding experiments with careful feeding showed that the humidity did not affect the way in which fertilised females produced larvae, for every female which had been fertilised, was fed adequately and kept at a suitable temperature, produced larvae at regular intervals.

The Activity of the Tsetse Fly.

In this section experiments are described showing how various factors influence the activity of adult tsetse-flies.

Manifestation of Hunger.

A number of male flies from a mixed laboratory culture were put into a large cage 1 × $1\frac{1}{2}$ × 2 metres. When I put in my hand, some of the flies immediately flew towards it and attempted to feed. They were caught and analysed, as were also a number of the other flies from the cage. Those which appeared to be hungry weighed on an average 26·4 mg., 32·04 per cent. of which was dry matter. The non-hungry flies weighed 30·3 mg., with 33·0 per cent. dry matter. The difference in dry matter was almost entirely due to the reserves of fat in the non-hungry flies which had an average amount of 1·60 mg., while the hungry ones had less than a quarter of that amount—0·36 mg. This experiment was repeated many times, and every time the flies which behaved in a " hungry " manner contained less fat than those which did not.

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* Males will fly up to pregnant females as if to copulate, but make no persistent attempt. In the case of a non-pregnant female they may try for several minutes if it is reluctant.

† Dissection of wild flies caught during the wet and dry seasons all showed that every female over a week old was fertilised.

Experiments described above (p. 619) show that in dry air tsetse-flies lose more water than in moist, but they use up their reserves at the same rate whatever the humidity (at the same temperature). It was thought that dry air, by raising the proportion of dry matter in the flies' bodies, might cause them to be hungry (thirsty ?) more quickly than would moist air, and they would come to the hand when still containing considerable reserves of fat under dry conditions. Various flies were fed, and then put into cylinders kept at either 19 or 65 per cent. relative humidity ; 24 hours after feeding, and then at intervals of about 12 hours, they were all let out into cages for 5 minutes, and those which came to the hand and tried to feed were killed and analysed. As soon as any flies at the lower humidity were found to have been enfeebled by desiccation the remainder at both humidities were discarded.* The following results were obtained :—

1. Using males which had had one feed only.
   At 19 per cent. R.H., 12 hungry, average fat 1·01 mgs. (S.E. 0·08).
   At 65 per cent. R.H., 10 hungry, average fat 0·95 mgs. (S.E. 0·13).
2. Using females which had had one feed only.
   At 19 per cent. R.H., 13 hungry, average fat 0·77 (S.E. 0·08).
   At 65 per cent. R.H., 10 hungry, average fat 0·74 (S.E. 0·10).
3. Using a mixture of males and females. One feed only.
   At 19 per cent. R.H., 11 hungry, average fat 0·74.
   At 65 per cent. R.H., 17 hungry, average fat 1·00.
4. Using wild males, caught and fed.
   At 19 per cent. R.H., 7 hungry, average fat 0·57.
   At 65 per cent. R.H., 9 hungry, average fat 0·59.

These figures show that desiccated flies do not become hungry any sooner than do those which are kept in fairly moist air. " Thirst " as distinct from " hunger " does not appear to be of importance to the tsetse.

Temperature and activity.

1. *Feeding.*—An apparatus was constructed to find at what temperatures flies would go and seek for food. It consisted of a large net cage 60 × 60 × 80 cm., which contained a live chicken fastened to the floor. A smaller cage 15 × 15 × 25 cm. was attached to one side of the large cage, and the partition between them could be removed. The flies were placed in the small cage, with the partition separating them from the chicken. The whole apparatus was put inside an incubator with the glass door only closed, and left until the temperature everywhere except in the immediate vicinity of the chicken was approximately the same (about half an hour). The small cage was facing towards the light, and the tsetses rested almost always on the outer (light) side. Then the partition was removed (without opening the incubator), so that a hungry fly which wished to seek for food would be able to go and find the chicken. The results were considered disappointing until it was realised that the whole of the walls of the larger cage were being " bitten " and it was impossible to expect a large proportion of the flies to feed in half an hour, although all the flies used were " hungry." Eventually 20 flies were used in each experiment, and if

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* Otherwise the remaining flies at 65 per cent. R.H. would have been exposed for a different (longer) period.

two* fed it was considered "positive"; if only one, "doubtful"; and if none, "negative." All experiments below 20°C. were negative, and practically all between 21° and 27°C. were positive. There were a number of doubtfuls between 20° and 21°C. It appeared that the temperature had to be above 20°C. (preferably above 21°C.) before the flies would go and try to feed. It was not possible to work above 27°C., as with the apparatus at my disposal I could not get a uniform temperature throughout the cages at high temperatures. In some experiments the humidity was between 90 per cent. and saturation and in others as low as 65 per cent. This did not affect the results.

2. *Spontaneous flying.*—Using the apparatus described for the feeding experiments, it was observed that the flies never flew without an external stimulus at temperatures below 20°C.

3. *Flying when stimulated.*—A cage that could be shaken without opening the incubator was used. Between 20° and 14°C., if the cage was shaken, the flies took short flights, but soon settled down again. Below 14°C. they fell to the bottom of the cage. They were still able to crawl. The temperature was reduced by one degree per half-hour. The flies flew again in a few seconds when transferred from 14° to 25°C.

4. *Crawling.*—The behaviour below 14°C. was investigated in a glass flask immersed in water. Crawling stopped at 10°C., and between 10° and 8°C. slight kicking was observed. Below 8°C. the flies were quite motionless. When transferred from 8° to 25°C. they recovered in about 30 seconds, buzzing hard as they did so. This buzzing was not seen in flies which had only been cooled to 10°C., so it cannot be to warm the tsetse to enable it to fly (confirms Buxton & Lewis' (1934) comment on Macfie's (1912) observation). Some flies fed within two minutes after 3 hours at 8°C.

No experiments were made at lower temperatures, as *palpalis* is never subject to them in nature. Macfie (1912) found that a few minutes' exposure to 2·5°C. was harmful.

The results obtained may be tabulated as follows :—

21°C.	Lowest limit of spontaneous flight and food-seeking.
14°C.	Limit of flying when stimulated to do so.
10°C.	Limit of crawling.
8°C.	Quite motionless below this temperature, but recover quickly.

General activity and flight.

The experiments described in this section are rather crude and inexact, but are perhaps of sufficient importance to include here, if only because they indicate what may prove important lines for future research.

Ten flies were put into a cubical gauze cage, each side of which was 9 inches. The temperature, humidity and light in the cage were then measured, and the number of individual spontaneous flights taken in five minutes was recorded. These flights usually lasted about a second, after which the fly settled down to rest on the gauze once more. There was a good deal of variability, but there was no doubt that the results obtained under different conditions were distinct from one another. For instance, under one set of conditions a batch of flies took the following number of flights in consecutive experiments :—38, 26, 56, 38, 33. On other occasions a batch would never take less than 84 or more than 130 flights, or others might always take less than 5.

I do not believe that these results are sufficiently accurate for us to be able to compare the activity of different batches of flies under different conditions, and estimate the effects of the different conditions on a strictly numerical basis. However, the following conclusions were certainly apparent :—

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* Seven was the largest number which ever fed.

1. With constant conditions of temperature and light (humidity did not appear very important within the range in which I worked), the hungrier the fly the more active it became. For instance, the average figures obtained with a batch of old males were as follows : day of feeding, no flights ; day 1, 3 flights ; day 2, 8·5 flights ; day 3, 26 flights ; day 4, 36 flights ; day 5, 52 flights. These observations were all made at a temperature of about 25°C., under light shade.

2. Below 21°C. there was very little activity (none below 20°C., see p. 626). As the temperature rose above 21°C., the activity increased. For instance, one batch of male flies gave an average number of flights of 129 at 35°C., and of only 55 at 27°C.

3. Increasing the light intensity increased the activity, and direct sunlight caused intense activity as a rule.

4. Newly emerged (unfed) females were much more active than newly emerged males. Both sexes were more active during the second than during the first day of adult life. After two days some individuals became too weak to fly. Older females (whether unfertilised or pregnant) were comparatively inactive unless very hungry.

5. Newly emerged flies were kept for 24 hours in dry and in moist air. This is sufficient to alter their water to dry matter ratio, but does not appear to affect their activity. The " desiccated " and " undesiccated " flies were equally active. (The experiment was repeated later with four different batches of flies. Twice the flies from the lower humidity appeared a little more active, and twice those from the higher.)

Reaction to Light.

In the laboratory, flies in cages were nearly always found to rest at the end nearest the window. If there was a window at either end of the room, and both were uncovered, flies were seen to rest at both ends of the cage. If one window was then covered, the flies all went to the other end. They did not fly there at once, but when they took spontaneous flights, which might not happen for many minutes, they usually stopped flying and rested at the light end of the cage. By changing the direction of the light they could be made to migrate backwards and forwards. This experiment was made using flies which were "used to captivity." Some flies, particularly newly-caught wild ones, exhibit intense activity and keep beating themselves against the walls of the cage. Those which survive for a few days seem to settle down to a more placid existence, but this initial activity of wild flies may account for some anomalous results obtained in laboratory experiments. From field observations I should say that there wild flies behave in the more " placid " manner.

The reaction of *Glossina palpalis* to sunlight is interesting. A large cage was erected so that one end was in direct sun, and the other in dense shade. The flies all flew into the sunlit end. Very soon they appeared to exhibit discomfort, and flew again. If they settled in the darker parts of the cage, they soon flew out again into the sunlight. If they settled near the edge of the sunlight, they appeared to be more comfortable, and in about half an hour all the flies were found to have congregated in a band at the edge of the sunlight. None were resting in the darker parts, and none stayed long in the direct rays of the sun. They appeared to find this " optimum zone " of light intensity by a method of trial and error, and it was the brightest intensity of light which they could comfortably stand. This observation compares with one which is easily made in the field—that *G. palpalis* is often found resting in the sun flecks near the edge of a clearing, but seldom in dense forest under a heavy canopy. If all species of testse behave in a similar manner, the strength of their light optima (the most powerful light which they can stand with comfort) may help to explain their distribution.

This work on the behaviour of the fly is still in a very elementary stage, but I hope that I have shown that it is a very promising field for research.

Experiments using Puparia.

The reactions of the puparium to climatic factors were also investigated. Laboratory pupae under 24 hours old were used. They were on the average 30 per cent. smaller than wild pupae, but over 70 per cent. of them were found to be viable under favourable conditions.

Table XI summarises some results obtained when using such pupae and keeping them under controlled conditions until they emerged. The humidity did not affect the time taken in development, average figures for which are as follows: at 30°C., 22 days (insufficient numbers to make sexual differences, etc., significant); at 24°C., for females 31·1 days and for males 33·1 days (difference statistically significant); at 20°C., all flies emerged on the 64th day. It is possible that they may have been ready to emerge earlier at 20°C., and actually came out when the temperature was slightly higher. This point was not investigated, but is suggested by the emergence of all the flies, of both sexes, on the same day.

TABLE XI.

Percentage of laboratory-produced Pupae which emerged, and which developed fully, under constant Conditions.

Temp. °C.	R.H. %	Emerged %	Developed fully % *	Total number
30	100	43	83	23
	88	6	94	16
	65	—	63	27
	44	—	15	13
	19	—	6	18
24	100	45	45	20†
	88	76	88	41
	65	61	71	43
	44	—	58	34
	19	—	10	20
20	88	73	77	24
	65	27	45	11
	44	—	43	14
	19	—	—	13

* This includes flies which emerged and which developed fully but could not emerge from the puparium.

† Much mould developed.

All the pupae were weighed individually at frequent intervals. They lost weight rapidly for the first four or so days, during which time they could be shown by dissection still to be in the pre-pupal stage, with the tracheae attached to the spiracular plates. When pupation took place the rate of loss decreased greatly in all unless they died early on. Many individuals, particularly at the lower humidities, developed successfully, but were not able to escape from the puparium. This appears to be because they lost too much water in the early part of the experiment, for individuals desiccated for a few days after formation and then put into moist air went on developing but never emerged, whereas others put into dry air for the last half of the pupal period emerged successfully.

These results may be compared with those obtained by other workers. Buxton & Lewis (1934) found that *Glossina tachinoides* and *submorsitans* have pupae which behave in essentially the same way, except that they survive a higher temperature better, and are more resistant to desiccation. This is what one would expect from species which live in much hotter and drier regions than *palpalis*. Potts (1936) found that *G. swynnertoni* pupae are less affected by desiccation, and they also are found under drier conditions.

In saturated air moulds are apt to form and harm the puparia if they are merely exposed in open tubes. In some later experiments they were buried in sand, the air in the spaces of the sand being saturated. No moulds developed, and a high proportion of flies emerged. This was to be expected, for I found that the air in the soil spaces from every place in which I found pupae—even with soil some distance from the lake in dry weather—was saturated. This was true of soil which appeared " quite dry " when handled.

In the drier air, only the larger pupae developed successfully, while in moist air small pupae produced adult flies. As wild pupae are usually larger than laboratory ones, they will be even better at withstanding desiccation.

Potts (1936) found that flies from laboratory pupae (of *Glossina morsitans* and *swynnertoni*) were not only smaller than those from wild ones, but also that they contained a much smaller *percentage* of fat. This is true of *palpalis* also. Flies which had recently emerged from wild pupae contained on an average 1·56 milligrams of fat, which is 22·4 per cent. of their dry weight. Flies recently emerged from laboratory-produced pupae contained only 0·865 mg. of fat, which is 16·7 per cent. of their dry weight. It is best to express these figures as percentages of the dry weight rather than of the live weight, for the quantity of water, but not of dry matter, varies greatly, depending whether the pupae have been kept in dry or in moist air. Also newly-emerged flies eliminate a good deal of water in the first day of their adult life.

If the flies produced from laboratory pupae are divided into two batches, one containing those heavier than the average and another those which are smaller, the following results are obtained : larger flies, fat 1·10 mg., 18·4 per cent. of dry weight ; small flies, fat 0·61 mg., 13·8 per cent. of dry weight. In other words, the smaller the flies, the lower the proportion of fat. Examination of analyses of flies from wild pupae shows that this is true of them also, and suggests that the laboratory-bred flies contain so little fat because they are so small. Some pupae which had been newly produced were next analysed, and it was found that the larger and smaller contained about the same percentage of fat. Apparently the rate of metabolism* (and fat-consumption) of small and large pupae is about the same, and a small pupa produces a small fly after using up almost all its reserves. A large pupa produces a large fly with still some reserves left. Very small pupae appear to use up all their reserves before metamorphosis is complete, and so never produce adults.

The conclusion arrived at above was confirmed when using *Lucilia*. Maggots which were not fully grown were removed from meat, when they pupated and eventually produced small flies. These had a less weight of fat, and also a smaller proportion than had (larger) flies whose larvae were allowed to feed until they left the meat voluntarily.

As pupae lose weight during development, it is only possible to find the initial weight of wild ones by a roundabout method. Using laboratory pupae, it was found that the ratio of the fat-free dry weight to the initial pupal weight was the same for both small and large pupae. Presumably it is the same for the (even larger) wild pupae. Pupae averaging 27·60 mg. produced adults with an average fat-free dry weight of 4·31 mg. The average fat-free dry weight of adults newly emerged from wild pupae was 5·39 mg. Let x be the weight of a wild pupa at the time of production, then

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* The actual rate, not the rate per gram.

$$\frac{27{\cdot}6}{4{\cdot}31} = \frac{x}{5{\cdot}39}$$

and so we infer that the wild pupa weighs 34·5 mg.

The Behaviour of the Larva.

It is impossible to do many experiments using the active larva of the tsetse-fly, as this stage lasts for such a short time. But it is perhaps the most vulnerable stage in the life-history and is therefore worthy studying.

Lewis (1934) showed that the tsetse larva could only burrow satisfactorily into coarse sand containing pebbles, and that unless the mother dropped it in a place with a suitable surface the larvae pupated above the ground and was probably killed. Nash (1933) showed that direct sun can kill a pupa even if it is buried 1½ inches below the surface, so that it is important that pupae should lie in shaded places. I have investigated the larva's reaction to light, and find that it is not phototropic. If an actively crawling larva is put into a beam of light, the direction of its movements is unaffected by the direction of the beam. This means that if the larva were not deposited in a shady place it would have no means of finding one. This emphasised the importance of the female's ability to find a suitable spot for larviposition, while the inability of the larva to crawl far prevents it from moving to a dangerous region.

Climatic Conditions in the Field.

The lake-shore areas of Uganda have a uniform climate, which varies little throughout the year. The " wet " and "dry " seasons are ill-defined, and almost every year is climatically abnormal. During all seasons the night temperature is in the region of 15°C., and the air is saturated for several hours. The day temperature may only rise to 22°C., if it is dull, cloudy or wet, and it rarely rises as high as 30°C. on the hottest day.

The relative humidity falls to between 70 and 50 per cent. during the middle of the day. Using the saturation deficiency notation, the mean figure for a dry day during the rainy season in 1935 was 3·2 mm., and 5·7 mm. for a day during the dry season. The saturation deficiency was never higher than 16 mm. even for a few hours, and among foliage it never rose even to that level.

With a climate such as this, the microclimate to which the insects are subjected in the field varies little from the climate measured by the meteorologist, for the temperature is less than one degree lower in fly-infested bush than inside a Stevenson screen, and the humidity in the bush is slightly greater. It is therefore surprising that Carpenter (1911) obtained results which suggested that a dry spell of weather will reduce the longevity of *G. palpalis*, for " dry " weather in Uganda is really so very " moist." My laboratory experiments indicated that a relative humidity of 65 per cent. at a constant temperature of 24°C. does not cause harmful desiccation. The mean saturation deficiency under these conditions is 8·0 mm., which is considerably greater than that found in the field even during very dry weather. It appears probable that some other factor than desiccation must be at work in reducing the numbers of the flies.

The climatic conditions in Uganda are very different from those investigated by Buxton & Lewis (1934) in Northern Nigeria. There they found that during the hot, dry season the temperature was for several hours in the neighbourhood of the fly's thermal death-point, and the air was extremely dry. The mean saturation deficiency was as great as 20 mm. during the month of April, and for several hours a day was more than twice that figure. *Glossina palpalis* would be unable to withstand conditions such as these, but at present it is difficult to understand why the dry season in the regions around Lake Victoria should be unfavourable to this tsetse, for the conditions are always comparatively moist.

Summary.

The general conclusion arrived at after examining the results obtained by subjecting *Glossina palpalis* to different humidities is that though excessive desiccation is harmful, yet the fly is able to withstand far drier conditions that it is ever likely to meet in the field. It appears unlikely that, for instance, the seasonal fluctuations in numbers round Lake Victoria are due to harmful effects of the dry season. There is also no evidence that very moist air is itself harmful.

Experiments to determine the time flies could survive without food under various conditions of temperature and humidity showed that the rate at which water is lost is fairly slow, so that except in very dry air flies die from starvation before desiccation proves fatal.

Breeding in the laboratory is unsatisfactory, because of difficulties in persuading flies to feed regularly.

The readiness with which flies feed, and the amount of blood which they take, is not affected by humidity.

The rate of metabolism is the same in dry and moist air. In dry air water is lost more rapidly than in moist, which upsets the dry-matter : water ratio, but a blood meal contains so large an excess of water that it can replace any deficiency. It is possible to show that *G. palpalis* exhibits a regular hunger cycle, in which the hungry fly has an empty gut and a small fat-body. Two days or so after feeding the gut is nearly empty, and the fat-body is at its maximum size. Then the fat decreases and the fly becomes hungry once more. It is only when the air is very dry that death occurs from desiccation before the fat has all been metabolised (when normally the fly becomes hungry and seeks food). *G. palpalis* can withstand one hour at 41°C. in moist air, and can cool itself by evaporation sufficiently to withstand 42°C. in dry air. It can withstand 39°C. for 3 hours in air of all humidities. These temperatures are above those occurring within its normal range.

It is possible to see living sperm in the spermatheca of a fertilised female tsetse. Even in the presence of males, females in laboratory cultures may avoid fertilisation for many weeks. The process of copulation is described. The presence of a high proportion of males does not cause abortion, for pregnant females are not persistently pestered.

Flies are not active, nor do they seek for food even if hungry, at temperatures below 21°C. Between 21° and 13°C. they can fly if disturbed, and between 13° and 8°C. they crawl or kick. Below 8°C. they are completely immobilised, though even after 3 hours at that temperature they can feed within 2 minutes of transference to 25°C.

Hungry flies are more active than those which are not. Increased light intensity and a raised temperature promote activity. Flies seem to be attracted by light, and there is an optimum light intensity, which is about a third the intensity of sunlight.

Pupae develop best in moist air. In fairly dry air adults are unable to escape from the puparia. In all places where I found wild pupae, the air in the soil spaces was saturated, though the soil appeared to be dry.

The active larvae show no reaction to light.

References.

Buxton, P. A. & Lewis, D. J. (1934). Climate and tsetse flies : laboratory studies upon *Glossina submorsitans* and *tachinoides*.—Phil. Trans. Roy. Soc. Lond. (B), **224,** pp. 175–240.

Buxton, & Mellanby, K. (1934). The measurement and control of humidity. —Bull. Ent. Res., **25**, pp. 171–175.

Carpenter, G. D. H. (1911). Progress report of investigations into the bionomics of *Glossina palpalis*.—Roy. Soc. Rep. of S.S. Com., **12**, pp. 79–111.

Jackson, C. H. N. (1933). The causes and implications of hunger in tsetse flies.—Bull. Ent. Res., **24**, pp. 443–482.

Lewis, D. J. (1934). The behaviour of the larvae of tsetse-flies before pupation.—Bull. Ent. Res., **25**, pp. 195–200.

Macfie, J. W. S. (1912). Experiments and observations upon *Glossina palpalis*.—Bull. Ent. Res., **3**, pp. 61–72.

Mellanby, H. N. (1937). Experiments on the reproduction of the tsetse-fly, *Glossina palpalis*.—Parasitology. (In press.)

Mellanby, K. (1932). The influence of atmospheric humidity on the thermal death point of a number of insects.—J. Exp. Biol., **9**, pp. 222–231.

—— & Buxton, P. A. (1935). A toxic emanation from rubber.—Nature **136**, p. 873.

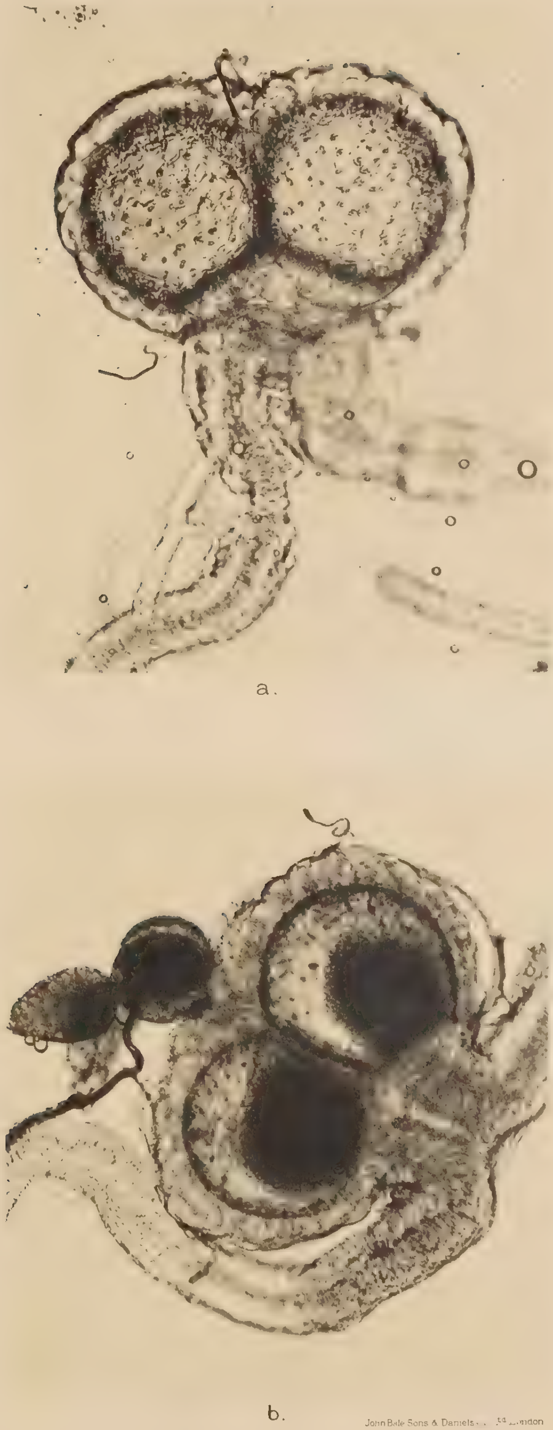
Minchin, E. A. (1905). Report on the anatomy of the tsetse-fly (*Glossina palpalis*). —Proc. Roy. Soc. B, **76**, pp. 531–547.

Nash, T. A. M. (1930). A contribution to our knowledge of the bionomics of *Glossina morsitans*.—Bull. Ent. Res., **21**, pp. 201–257.

Nash, T. A. M. (1933). The ecology of *Glossina morsitans*, Westw., and two possible methods for its destruction. Part 2.—Bull. Ent. Res., **24**, pp. 163–198.

Potts, W. H. (1936). Work by Potts described by Swynnerton (1936, pp. 175–195).

Swynnerton, C. F. M. (1936). The tsetse flies of East Africa.—Trans. Roy. Ent. Soc., **84**, pp. i-xxxvi, 1–579, 22 pls., 7 maps.



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The spermatheca of *Glossina palpalis*, (a) From a virgin fly, (b) from a fly which has been fertilised. Note masses of sperm in (b)

OBSERVATIONS AND EXPERIMENTS ON *AËDES CONCOLOR*, TAYL. (DIPT. CULIC.).

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Introduction.

The mosquitos of the Australian region have been extensively studied from the taxonomic aspect, and a number of workers, including Taylor (1914, 1928, 1929, etc.) Mackerras (1926), Cooling (1924), and Hill (1922), have recorded in general terms the types of water in which the larvae of various species are found. With the exception of the work carried out by Hamlyn-Harris (1927–28–30–33), however, no detailed studies have been made of the possible chemical, physical, or biological factors which may limit particular species of larvae to the special type of water in which they develop.

The most important pest species in the Sydney district are probably *Culex fatigans*, Wied., *Aëdes* (*Ochlerotatus*) *vigilax*, Skuse, *Aëdes* (*Finlaya*) *notoscriptus*, Skuse, *Aëdes* (*Mucidus*) *alternans*, Westw., *Aëdes* (*Finlaya*) *alboannulatus*, Macq., and in restricted localities *Aëdes* (*Pseudoskusea*) *concolor*, Taylor. Of these *A. vigilax*, *A. alternans* and *A. concolor* breed commonly in various concentrations of sea-water. *A. concolor* was selected for study owing to its strict limitation to a particular habitat, in the hope that some information might be gained as to the factors responsible for this limitation. In addition nothing has so far been published on the bionomics of this species, which is a particularly interesting one from the ecological and physiological aspects. A discussion of the general position with regard to mosquito ecology is hardly necessary here, since numerous authors have given excellent summaries and bibliographies up to the time of publication of their work, and original papers are appearing at frequent intervals. The majority of the work on mosquito ecology, with certain notable exceptions, has so far been carried out by means of water analysis (both chemical and biological) and field observations, correlated with the occurrence of different species of larvae. While it is recognised that any ecological generalisations, if they are to be accepted, must agree with the observed conditions in the field, nevertheless laboratory experiments, in which a single factor only is varied, should yield considerable information. It is mainly along these lines that the present investigation has been commenced. While the information so far obtained as to the factors limiting the occurrence of *A. concolor* has been largely negative, still it is hoped that the data obtained are of sufficient general interest to warrant publication. The work will be continued if possible over a number of years.

General Bionomics.

The salt-water mosquito *Aëdes* (*Pseudoskusea*) *concolor* was described by Taylor (1914) from specimens bred from larvae found in the vicinity of Sydney, and has since been recorded from other parts of the New South Wales coast, from Norfolk Island, and from Tasmania (Taylor 1934). The adult has been shown by Heydon (unpublished) to be a favourable host, under experimental conditions, for a species of *Dirofilaria* in dogs. No description of the larva has been published, but it can be readily distinguished from other larvae of the genus *Aëdes* occurring in New South Wales by the fact that the anal papillae* are represented only by four minute globular swellings, which, in the living specimens, do not protrude beyond the apex of the terminal segment.

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* The term "anal papillae" is used throughout for "anal gills," since Wigglesworth (1933 b) has shown that the main function of these structures is not respiratory.

Larval Habitat and Food.

The larvae, as previously recorded by Mackerras (1926), are found only in one very definite type of naturally occurring water, *i.e.*, in rock pools at, or slightly above, high-tide mark, both on the open coast and in sheltered estuaries. These pools are filled by salt-water splashings and spray and sometimes by fresh water, which reaches them as seepage or as surface water during rain. Being subject to alternate evaporation and replenishment either with salt or fresh water, the salinity of these pools varies enormously. Larvae are very frequently found in pools of S‰50 (S‰—total salts in grams per litre), but have been recorded in water ranging from S‰74 to S‰1. This environment appears to be almost identical with that described by Mathis (1929) for *Aëdes desbansi*, Séguy, from the coast of France near Toulon.

Ocean water on the coast of New South Wales has a salinity of approximately 35·5 grams per litre.* The pools in which larvae occur most frequently have a considerable deposit of organic detritus; field observations and laboratory experiments tend to show that this detritus is the main food of the larvae. The larvae of *A. concolor* have never been recorded in adjacent salt marshes, nor in any other type of naturally occurring fresh, brackish, or salt water.

Distribution of the Adults.

No exact data have been obtained as to the range of flight of the adults, but normally they are only found in large numbers within a few hundred feet of the shore.

Seasonal Occurrence.

Breeding occurs chiefly during the warmer months from October to April in the Sydney district. Overwintering takes place mainly as fourth instar larvae, but occasional development of pupae and adults and some egg deposition takes place during the winter months, from May to September. In the laboratory, oviposition has sometimes taken place with the temperature as low as 55°F. No exact experiments have been made to determine the temperature at which hatching takes place, but numbers of eggs kept at 50 to 60°F. from 1st May to 1st September remained viable and hatched when raised to 70°F. on 2nd September. It is, therefore, probable that in the field some overwintering may take place in the egg stage. During the warmest months, *i.e.*, January, February and March, enormous numbers of *A. concolor* larvae are present in the rock pools, especially when long periods of comparatively calm weather occur. Southerly gales, with the resultant high seas, scour out the majority of the pools and larvae can then be found only with difficulty.

Oviposition and Food of Adults and Larvae.

In the laboratory, adult females bred from pupae collected in the field will deposit large numbers of fertile eggs without a blood feed, the only food supplied to the adults being bananas, apples and dates. Adults bred from larvae developed in the laboratory, on a food rich in protein (see Laboratory Methods), will also deposit fertile eggs without any food except fruit. Both males and females feed very readily on fruit juices when blood is not available. The organic detritus found in the rock pools consists to some extent of the remains of crustaceans and molluscs and is probably rich in protein. Experiments comparable to those carried out by Roubaud (1931–1934), Hecht (1932), de Boissezon (1933), and others, in the differential feeding of adults and larvae should yield interesting results with this species. Adults in every instance have been supplied with fruit, so that it is not possible to state at present whether the species is of the true autogenous type as described by Roubaud (1930). The species is certainly of the "stenogamic" type as defined by the same author, copulation taking place readily in cages 18 in. × 12 in. × 12 in. Virgin females frequently deposit large numbers of non-fertile eggs.

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* The methods used to determine the salinity are described under "Laboratory Methods."

Length of Life-Cycle.

At temperatures of 70 to 80°F. the following developmental periods were noted, the larvae being bred in sea-water plus dried fish food and the adults fed on fruit :—

Incubation period of eggs	5 to 7 days
Larval stage	14 to 19 ,,
Pupal stage	2 to 4 ,,
Total period egg to adult	21 to 30 ,,
Pre-oviposition period	7 to 9 ,,
Total period egg to egg	28 to 39 ,,
Maximum longevity of unmated females	108 days
Maximum larval period (hibernating)	96 ,,

Accurate studies of the effect of temperature changes on the development were not carried out.

Laboratory Experiments.

It will be seen from the preceding account that *A. concolor* has a very definite and restricted larval habitat and can develop in water of very high salinity. In addition it seemed likely that it could also withstand very sudden changes in the salinity of the water. In the following series of experiments an investigation has been made on the ability of the larvae to develop into adults in different types of water of known physical and chemical properties, a constant food being used throughout.

Laboratory Methods.

A. concolor has proved to be an excellent laboratory insect. Large numbers of fertile eggs can be readily obtained under laboratory conditions by liberating several hundred males and females in a cage 3 ft. × 2 ft. × 1 ft. 6 in., provided that the temperature is kept up to 70°F. and a high humidity is maintained. Adults were fed throughout on apples, dates and bananas, and oviposition was obtained on small pieces of filter paper partly immersed in water.

In all the following experiments the eggs were deposited on filter paper in distilled water and the larvae were transferred to the desired environment within a few hours after eclosion from the egg. A standard larval food was used throughout. This consisted of a very finely powdered mixture of oatmeal, wheatmeal, rice flour, dried prawns, dried eggs and meat meal. The mixture is sold locally as food for gold fish, etc., and contains very fine particles which the recently hatched larvae can readily ingest. Its chemical composition is as follows :—Ash 5·24 per cent. ; fat 8·77 per cent., protein 30·36 per cent., carbohydrates (including crude fibre) 55·59 per cent.

A partial analysis of the ash gave the following results :—NaCl 5·23 per cent. ; KCl 8·70 per cent., $MgCl_2$ 24·50 per cent., $CaCl_2$ 16·20 per cent., SO_4 17·20 per cent.

Other possible salts were not determined, but in a complex organic mixture of this type it is almost certain that traces of all the elements usually necessary for animal metabolism will be present.

The larvae were reared from the egg stage in lots of 20, in 150 cc. of water plus approximately ·05 gm. of fish food, which was first thoroughly wetted by agitation with a small quantity of water. The food and water were changed twice a week to eliminate excessive bacterial development and consequent fouling of the water. In changing the food and water the larvae were transferred to a large quantity of the clean water by means of a small pipette, the breeding jar was washed and filled and the larvae replaced, so that practically none of the original water was carried over. Some mortality frequently occurred in the experimental series, probably due to some injury sustained by the larvae during handling, but usually 80 to 100 per cent. developed to adults. The estimation of results was made throughout on the number of living healthy adults which emerged. Thus the whole of the larval and pupal periods were passed in the desired environment.

The salinity of the sea-water in the rock pools was determined by titrating the chlorides with silver nitrate and multiplying the result by the correct factor to give the total salts present, according to the method given by Harvey (1928). Where sea-water was allowed to evaporate, the titration method was used with water up to S‰130. Above this concentration precipitation of some of the salts commences to take place, and the titration method, which depends on the constant proportion of chlorides to other salts in sea-water, can no longer be used. For water above S‰130 therefore, the total salts were estimated by evaporating at 100°C., drying at 200°C., and weighing. Results by drying at this temperature were not completely accurate, but were found to be correct to within 1·2 gm. per 1,000 cc. Determination of the hydrogen ion concentration was first made approximately by means of the B.D.H. universal indicator and then by a Hellige Comparator giving a reading correct to 0·2.

The Larval Food.

Various types of food were tried including dried serum as used by Wigglesworth (1933 c) for larvae of *A. aegypti.* The serum was dialysed before drying in order to eliminate the mineral salts present, but it was found that the serum completely dissolved in sea-water or diluted sea-water, and this introduced the vexed question of the utilization of colloidal substances as food by mosquito larvae (Hinman, 1932 a, b). The ideal food for experiments of this type would be particles of non-soluble carbohydrates and proteins, completely free from mineral salts. A food of this type could not be obtained, and the fish food above described was used throughout this investigation.

In order to ascertain whether the addition of this standard food to the water was essential for the development of the larvae, the experiments shown in Table I were carried out.

TABLE I.

Eggs hatched in Distilled Water. Temperature 70–80°F.

No. of separate experiments	Total number of larvae	Food and water	Total adults emerged	Percentage adults emerged	Larval and pupal period in days
6	120	Filtered natural sea-water + fish food	108	90	17 to 23
4	80	Filtered natural sea-water—no food	0	0	—
6	120	Natural sea-water + natural organic detritus from rock pools	112	93	18 to 22

The filter used was an ordinary fine chemical filter paper (Whatman No. 5).

It will be seen that the artificial food gave results comparable to the natural detritus, and that no adults developed in the filtered sea-water without food. The larvae without food, however, remained alive for periods varying from 1 to 3 weeks, some even passing through the first ecdysis, but all died during either the first or the second instar, with very little increase in size.

Development in Diluted Sea-water.

As has already been stated, larvae have been observed in the field in water of S‰1, but it was not known whether the whole of their development took place in water of that type, as the salinity of the rock pools is constantly changing. A series of laboratory experiments was therefore carried out to determine whether the larvae could develop in various dilutions of sea-water with tap-water, or in tap-water alone. The results are set out in Table II.

TABLE II.

Eggs deposited in Distilled Water ; Larvae transferred immediately after Hatching and being fed with Fish Food.

No. of separate experiments	Total larvae	Type of water	Total adults emerged	Percentage adults emerged
3	60	Natural sea-water S‰ 35·5	55	91
1	20	Natural sea-water diluted with tap-water to S‰10	20	100
1	20	Natural sea-water diluted with tap-water to S‰5	20	100
4	80	Tap-water S‰0·062 ...	68	85

It will be seen that larvae can develop to adults in any dilution of sea-water, and even in tap-water. Many hundreds of larvae were subsequently bred through to maturity in tap-water. The average composition of the Sydney tap-water as given by the Metropolitan Water Board is as follows :—

Calcium carbonate	0·985	parts	per 100,000
Magnesium ,, ...	0·229	,,	,,
,, sulphate	0·562	,,	,,
,, chloride	0·091	,,	,,
Sodium ,, ...	3·184	,,	,,
Potassium ,, ...	0·421	,,	,,
Iron, alumina, silica, nitrates, phosphates, etc.	0·728	,,	,,
Total	6·200	,,	,,

Its salinity is therefore 0·062 per litre, as compared with S‰35·5 for sea-water.

Development in Concentrated Sea-water.

Experiments were also carried out to determine the maximum concentration of the salts in sea-water at which larvae of *A. concolor* would develop to adults. Large numbers of larvae in all stages were collected in natural sea-water with abundant organic detritus, and the water allowed to evaporate naturally in the sun and wind. As the water evaporated it was replaced by sea-water, and by this means it was possible gradually to raise the salinity from S‰35 to S‰200 within two weeks. No counts were made of the larvae originally present in the water, but 26 larvae pupated at S‰142 and from these 21 adults emerged. In another experiment 20 larvae pupated at S‰180 and from these 6 adults emerged. In a third experiment 20 fourth instar larvae remained alive at S‰200 for 4 to 5 days but did not pupate.

At S‰100 and over the larvae could only submerge themselves by very vigorous swimming and, when they ceased active movement, rose immediately to the surface. It was, therefore, difficult for them to feed on the detritus at the bottom of the dish, and failure to pupate may have been due to lack of food as well as to the high salinity of the water.

These results agree in a general way with previous observations as to the resistance of certain species of mosquito larvae to high salinities (Mathis 1929, de Vogel 1907, Vogel 1927, Balfour 1921), but the figure S‰180 appears to be higher than any previously recorded, where development to the adult stage was noted.

Development of A. concolor *and* C. fatigans *in Distilled Water plus Fish Food.*

It was then decided to determine if possible whether any chemical and physical properties of the water were essential for the development of *A. concolor* larvae, with a standard food.

For this purpose it was necessary to commence with distilled water, and experiments were carried out to determine whether *A. concolor* would develop in distilled water plus fish food. As eggs of *C. fatigans* were available, some experiments were also carried out with this species with rather surprising results, as shown in Table III.

TABLE III.

Eggs deposited in Distilled Water; Larvae removed immediately after Hatching and fed with Fish Food.

No. of separate experiments	Total larvae	Type of water	*A. concolor*		*C. fatigans*	
			Total adults	Percentage adults	Total adults	Percentage adults
12	240	Distilled water ...	0	0		
1	20	Dist. water 90% Tap-water 10%	0	0		
1	20	Dist. water 50% Tap-water 50%	15	75		
1	20	Natural sea-water S‰35	20	100		
1	20	Tap-water	17	85		
4	80	Distilled water ...			63	78
2	40	Tap-water			37	92
2	40	Natural sea-water S‰35			0	0

It will be seen from Table III that larvae of *A. concolor* will not develop in distilled water, even when a food has been added containing protein, fat, carbohydrates and mineral salts. Actually the distilled water quickly loses its purity, since traces of mineral salts soon become dissolved, as shown by the following analysis.

Fish food (5·0 grams) was mixed with distilled water (300 ccs.) and allowed to stand for two days. The liquid was then filtered, evaporated to dryness, and the residue analysed.

Analysis.

Na	·0014 gm.
K	·0016 ,,
Ca	·0065 ,,
Mg	·0031 ,,
Cl	·0236 ,,
SO_4	·0134 ,,
P_2O_5	·0225 ,,

Total salts in solution ·0874 grams per 300 cc.

It was considered that toxic traces of copper might be present in water distilled in copper condensers, and eight out of the twelve experiments were carried out with water distilled over block tin condensers, and in two of the experiments the water was distilled over hard glass vessels. In addition many hundreds of eggs were allowed to hatch in distilled water plus fish food, but not a single larva passed into the second instar, the majority dying in 3 to 5 days. *Culex fatigans* larvae, however, developed quite normally in distilled or tap-water plus fish food, but, as was to be expected, died rapidly in sea-water, recently hatched larvae being killed within an hour. Many hundreds of *C. fatigans* were subsequently developed to the adult stage in distilled water.

This remarkable contrast between the two species demonstrates again the striking difference between the environmental requirements of different species of mosquito larvae. Further experiments with the behaviour of other species in distilled water should prove interesting.

It was obvious that larvae of *A. concolor* required certain physical, chemical or biological conditions present in sea or tap-water plus fish food, but absent in distilled water plus fish food. It was considered that the contrasting results might be due to (*a*) the difference in salinity, with which osmotic pressure would be correlated ; (*b*) the presence or absence of some inorganic salts necessary for metabolism which were not present in the fish food ; (*c*) the difference in pH acting directly or indirectly ; (*d*) the difference in the bacterial development and the rate of decomposition of the fish food ; or (*e*) some substance of the nature of a vitamin which was absent from distilled water but present in naturally occurring waters.

A number of experiments were therefore carried out in an endeavour to obtain information on the above points. As a first step a synthetic sea-water was prepared, using only distilled water and pure chemicals. The formula used was that given by Dakin & Edmonds (1931). This water was prepared as follows :—28·15 gm. NaCl, 3·67 gm. KCl, 5·51 gm. $MgCl_2$, 6·92 gm. $MgSO_4+7\ H_2O$.

The above salts were first dissolved in 900 cc. of distilled water and then 1·45 gm. of $CaCl_2+6\ H_2O$ were added. When the calcium chloride was dissolved, 0·25 gm. $NaHCO_3$ dissolved in a few cc. of water was added. A trace of iodine was then added and the whole made up to 1,000 cc. with distilled water. This gives a salinity of S‰35·7 and approximates closely to the physical and chemical properties of natural sea-water. " Artificial sea-water " refers to the above solution, and unless otherwise stated the solutions were not more than a few weeks old when used. Mixtures of various salts in the form of pure chemicals dissolved in distilled water were also used, and the results are given in Table IV.

It will be seen from Table IV that the addition of traces of iodine, iron and sodium bicarbonate to distilled water had no effect in promoting the development of the larvae, but that they developed normally in artificial sea-water either with or without iodine and sodium bicarbonate, and in artificial sea-water diluted to 1/5 normal.

In addition, a solution of $NaCl+CaCl_2$, in the same proportions as those in which these salts occur in sea-water, gave a 68 per cent. emergence of adults, while equal amounts of these salts used separately completely prevented development.

This is in agreement with the results obtained by Wigglesworth (1933 a and c) and others who have demonstrated that the destructive action of NaCl is neutralised by a divalent salt such as $CaCl_2$, when present in the correct proportion to give a " balanced solution," such as occurs in sea-water, and that the death of the larvae in a concentrated solution of NaCl is not due simply to the osmotic pressure.

It is also apparent that the failure of larvae to develop in distilled water plus fish food cannot be due to the absence of some naturally occurring substance of the nature of a vitamin which may be present in tap or sea-water, since development takes place in distilled water plus pure chemicals.

It may also be concluded that the failure to develop in distilled water plus fish food is not due to the lack of any inorganic substance necessary for metabolism, since Na, Ca, and Cl, are present in the fish food in comparatively large amounts. Also *C. fatigans* develops quite readily in distilled water without the addition of Na, Ca or Cl, and although there is obviously some marked physiological difference between the two species, it is hardly likely that *A. concolor* would require a very much greater amount of the above elements for its metabolic processes. Further experiments are required using various salts before this point can be satisfactorily settled.

TABLE IV.

Eggs deposited in Distilled Water; Larvae transferred immediately after Hatching and fed on Fish Food. Solutions of pure Chemicals in Distilled Water.

No. of separate experiments	Total larvae	Composition of water	No. of adults emerged	Percentage adults emerged
2	40	Distilled water	0	0
2	40	Tap-water	33	82
1	20	Dist. water + trace I	0	0
1	20	Dist. water + trace Fe	0	0
1	20	Dist. water + 0·25 gm. $NaHCO_3$ per litre	0	0
1	20	Artificial sea-water, standing 6 months	18	90
2	40	Artificial sea-water	29	72
5	100	Artificial sea-water, no I and no $NaHCO_3$	94	94
1	20	Artificial sea-water, diluted to 1/5 normal, *i.e.*, S‰ 7·1	18	90
2	40	NaCl 28·15 gm. per litre	0	0
2	40	$CaCl_2$ 28·15 gm. ,, ...	0	0
3	60	NaCl 28·15 gm. per litre + $CaCl_2$ 1·45 gm. per litre	41	68

Since Hinman (1933), Rozeboom (1935), and Trager (1935), had shown the importance of bacteria and yeasts, or substances produced by these, in the development of mosquito larvae, it seemed possible that the presence or absence of bacteria in sea, tap, and distilled water might be a factor. The usual quantity of fish food was, therefore, added to water which was then kept for 7 days at 70°–75°F. Counts of the number of bacteria per cc. were then made on standard agar plates after incubation at 90°F., with the following results :—

Natural sea-water ...	7,000	bacteria per cc.
Tap-water	3,875,000	,, ,, ,,
Distilled water	1,927,000	,, ,, ,,

While no detailed bacteriological studies have yet been made, the above figures indicate that considerable development of bacteria took place in distilled water plus fish food, so that absence of bacteria cannot be the cause of the death of the larvae in distilled water. On the other hand it is possible that some particular type of pathogenic bacteria or fungus may develop more readily in distilled water than in tap-water, and that this may be responsible for the death of the larvae, as recorded by MacGregor (1921) and Senior-White (1926).

Or again, the special type of bacterial activity in distilled water may give rise to decomposition products injurious to the larvae. In view of the work of Beattie (1932), Buxton (1934), Hamlyn-Harris (1930) and others, it appears essential that analyses of the tap and distilled water plus fish food should be made with reference to free ammonia, albuminoid ammonia, nitrites and nitrates.

With regard to the pH values of the water used in the experiments, distilled water gave a value of 5·8–6·2, tap-water 6·8–7·2, and sea-water 8·2–8·4. Twenty-four hours after the addition of fish food, however, the pH values of tap and distilled water were always practically equal, *i.e.*, 6·0–6·2, while the pH of sea-water was reduced to 7·6–7·8. The failure of the larvae to develop in distilled water cannot, therefore, be correlated with a difference in pH values of tap and distilled water.

There remains then the consideration of the osmotic pressure of distilled water plus fish food as compared with tap and sea-water plus fish food. Wigglesworth (1930, 1933 a and c) concludes that a solution of 1 per cent. NaCl is definitely hypertonic to the haemolymph of *Aëdes aegypti*, 0·9 per cent. is slightly hypertonic, and 0·5 per cent. hypotonic. The total salts in solution after 48 hours, when fish food is added to distilled water amount only to 0·0003 per cent., while the naturally occurring salts in Sydney tap-water average 0·0062 per cent. The total salts in tap-water plus fish food would, therefore, amount to ·0065 per cent., assuming that an equal amount of salts is dissolved from the fish food by tap and distilled water. Both distilled and tap water would, therefore, be hypotonic to the haemolymph, but it does not seem likely that the difference between the salt content of the two would be responsible for the failure of the larvae to develop in distilled water.

The addition of very minute quantities of a " balanced solution " of pure chemicals to distilled water should yield interesting results.

Changes in Salinity.

As mentioned previously it is obvious that larvae occurring under natural conditions must be subject to great changes in salinity, and experiments were carried out to determine the effect of abrupt changes in the salt content of the environment. Natural sea-water was used as a basis and was diluted with tap-water (taken as S‰0, actually S‰·06) to decrease the salinity. To increase the salinity the salts used in making up artificial sea-water were added, the proportions of the various salts being kept constant as in the formula given previously. In each experiment the larvae were transferred from one type of water to another within a few hours after ecdysis had taken place, any inaccuracy resulting from the transfer being eliminated by several changes of water. The results obtained are set out in Table V.

As shown in Table V the larvae can withstand abrupt changes in salinity, from a dilute to a very concentrated medium and in the reverse direction. Where fourth instar larvae are allowed to remain in S‰105 considerable individual variation occurs, some larvae becoming shrivelled and dying within 24 hours, while others survive and pupate. It would appear that some physiological adaptation takes place in the larvae when the salinity is gradually raised, since 60 per cent. of adults were produced from S‰105 in experiment 3, whereas in experiment 11, when a change was made directly from S‰0 to S‰105, all the larvae died.

A similar adaptation in *Aëdes aegypti*, in water of much lower salinity, has been accounted for by Wigglesworth (1933 c) on the grounds of changes in the structure and function of the cells of the anal papillae and mid-intestine. In *A. concolor* the anal papillae are vestigial (or rudimentary), but changes in the mid-intestine may possibly be of a similar nature to those described for *A. aëgypti.*

As shown in experiment 18, only a very small percentage of the larvae produced adults when changed from S‰35 to S‰0 (tap-water) in the fourth instar, although in experiment 2, 90 per cent. of adults were produced when the whole development took place in tap-water. The larvae swelled up slightly when first introduced into tap-water, but usually lived four or five days, dying just prior to or during pupation.

It is obvious that some adaptation takes place in larvae conditioned to salt water, and that this prevents their successful development when placed in tap-water, but until further work similar to that carried out with *A. aegypti* is undertaken, no conclusions can be reached as to the physiological processes involved.

TABLE V.

Larvae fed on Fish Food.

No.	No. of separate experiments	No. of larvae	Salinity in which various instars were passed—figures = S‰					No. of adults emerged	Percentage adults emerged
			Eggs and 1st instar	2nd instar	3rd instar	4th instar	Pupal stage		
1	1	20	35	35	35	35	35	15	75
2	1	20	0	0	0	0	0	18	90
3	2	40	35	70	70	105	105	28	60
4	1	20	35	35	35	70	70	18	90
5	2	40	35	35	35	105	105	21	52
6	1	20	10	10	10	35	35	20	100
7	1	20	10	10	10	70	70	16	80
8	2	40	10	10	10	105	105	15	37
9	2	40	0	35	35	35	35	38	95
10	2	40	0	0	0	35	35	40	100
11	2	40	0	0	0	105	*	0	0
12	1	20	35	70	105	70	70	16	80
13	1	20	35	70	105	35	35	16	80
14	1	20	35	70	105	10	10	17	85
15	1	20	35	70	70	35	35	20	100
16	1	20	35	70	70	10	10	20	100
17	1	20	35	35	35	10	10	20	100
18	3	60	35	35	35	0	0	12	20

* Larvae failed to pupate. S‰0 = Tap-water.

With regard to salt-water mosquitos studied by other workers, Mathis (1929) states that *Aëdes desbansi*, Séguy, will develop to the adult stage in fresh water or water containing 50 to 80 gm. NaCl per litre, that it can be changed at any stage from salt to fresh water, but is killed in water containing 100 gm. NaCl per litre. No details of the experimental work are given, and it is not clear whether the author is referring to a solution of NaCl or to sea-water.

On the other hand Legendre (1934) states that *Aëdes caspius*, Pall. (*punctatus*, Mg.), which breeds in sea-water containing 30 gm. NaCl per litre, cannot develop in fresh water, and that "large" larvae changed from sea-water to fresh water die within a few days. Apparently no standard food for the larvae was used by either of these workers.

Oviposition Responses.

Some preliminary experiments on the oviposition responses of *A. concolor* were carried out, and although no general conclusions can be drawn, the results were sufficiently striking to be of some interest.

From 300 to 400 adults were liberated in a cage 2 ft. × 2 ft. × 3 ft. and fed on dates and bananas. Oviposition took place on filter paper partly immersed in water, and counts of the eggs were made daily. In the first experiment four oviposition dishes were used, two containing distilled water and two natural sea-water of S‰ 50. The latter was not taken from the rock pools but was clean filtered ocean water, allowed to evaporate naturally; it therefore contained very little organic matter. This salinity (S‰50) frequently occurs in the rock pools. The humidity was kept at 75 per cent. to prevent evaporation, and the dishes were cleaned and their positions reversed daily. The second experiment was carried out in a similar manner, but filtered ocean water of the natural salinity S‰35·5 was used. The results are given in Table VI.

TABLE VI.

Experiment 1.

	No. of separate daily counts	Total no. of eggs deposited	Percentage of eggs deposited
Sea-water S‰50	15	3	0·2
Distilled water ...	15	1,738	99·8

Experiment 2.

	No. of separate daily counts	Total no. of eggs deposited	Percentage of eggs deposited
Sea-water S‰35	10	294	5·6
Distilled water ...	10	5,020	94·4

It will be seen from Table VI that the females exhibit a very definite preference for distilled water as compared with clean filtered ocean water of S‰50 or S‰35.

The only conclusion that can be drawn from this experiment is that *A. concolor* does not show a positive oviposition response to the presence of the mineral salts which occur in sea-water. The sea-water found in the rock pools contains abundant decaying organic matter which was not present in the sea-water used in the experiments.

Mathis (1934) working with *A. desbansi* found that approximately equal numbers of eggs were deposited on fresh water and water containing 30 gm. NaCl per litre, while comparatively few were deposited on water containing 60 gm. NaCl per litre, and practically none on water containing 100 gm. NaCl per litre. No indication, however, is given as to whether natural sea-water or a solution of NaCl was used, nor whether the fresh water was distilled or tap-water, and the possible content of organic matter in any of the waters used is not discussed.

Discussion, Conclusions and Notes on Other Species.

It is obvious that the larvae of *A. concolor* are specially adapted for existence in water which may vary from a low to a very high salinity. No other species have ever been found by the author in association with *A. concolor* in the typical rock pools of S‰10 to S‰70, but the larvae of *Aëdes* (*Finlaya*) *alboannulatus*, Macp., have occasionally been taken in association with *A. concolor* in rock pools containing water of very low salinity, *i.e.*, S‰1 to S‰4. This association has previously been recorded by Mackerras (1926), but the salinity was not stated, and it is very doubtful if *A. alboannulatus* ever occurs in water of high salinity.

Aëdes (*Ochlerotatus*) *vigilax*, Skuse, and *Aëdes* (*Mucidus*) *alternans*, Westw., which occur commonly in pools at the edge of salt or brackish swamps, have never been taken in the coastal rock pools, although their typical breeding pools may be only a few hundred feet away. Records of the salinity of water in which any species of Australian mosquitos breed are very scanty but Lee (unpublished) has recorded the following figures for some species :—

A. vigilax, S‰17·7 to S‰37·0
A. alternans, S‰7·0 to S‰21·7
A. alboannulatus, S‰2 to S‰7·0
Culex annulirostris, Skuse, S‰16·3
Anopheles (*Myzomyia*), *annulipes*, Walk., S‰16·3

The last three species are also found commonly breeding in fresh water, and Mackerras (unpublished) states that : "*A. alternans* has been found breeding in perfectly fresh water 100 miles from the coast, and *A. vigilax* has been found breeding in water of low specific gravity and only faintly peaty taste."

The common breeding waters of *A. alternans* and *A. vigilax*, however, are found close to tidal waters and show varying degrees of salinity.

Various workers (Vogel 1927 and Gibbins 1932) have recorded the reduction in size of the anal papillae of larvae breeding in salt water (both for separate species and races within a species) and Wigglesworth (1933 a, b, c) has shown that in *A. aegypti* the anal papillae are the only region of the integument freely permeable to water, and that the reduction or absence of these structures favours the resistance of larvae to high osmotic pressures.

It is of interest to note that in *A. concolor* the anal papillae are only represented by very minute concealed swellings, in *A. vigilax* and *A. alternans* they are very much reduced, and in *C. fatigans*, which quickly dies in water of S‰35, they are very well developed. On the information available it would appear that the mosquitos of the Sydney district could probably be approximately divided into three groups, as follows :—

1. Larvae able to develop in water up to S‰100 or over.
2. Larvae able to develop in water up to S‰35.
3. Larvae able to develop in water up to S‰10.

Detailed comparative studies of the salinity resistance of the various species correlated with the comparative size of their anal papillae should yield very interesting results.

With regard to the factors limiting the occurrence of *A. concolor* larvae to the coastal rock pools, it can be concluded from the preceding experiments that the presence of varying amounts of sea-water is not directly responsible for their limitation, since the larvae will develop in tap-water and the adults oviposit in distilled water in preference to pure salt water. Sea-water may, however, be indirectly responsible, since its presence in conjunction with the decaying organic matter may give rise to special conditions not found in swamps and pools, either fresh or brackish, in other situations. The particular type of organic detritus found only in the coastal rock pools may prove to be an important factor, combined with the development of micro-organisms and the presence of free and albuminoid ammonia.

The pH of the rock pools has not yet been systematically investigated, but preliminary laboratory experiments indicate that *A. concolor* will develop within a wide range of pH values. On the other hand the limiting factor may be entirely concerned with the oviposition responses, since, although the female prefers distilled water to pure sea-water, the presence of decaying organic matter in conjunction with sea-water may produce substances which attract the female for oviposition.

It will be seen, therefore, that a considerable amount of detailed investigation will be required before any further knowledge on these points can be obtained.

Although the actual limiting factors in the distribution of *A. concolor* have not been determined, nevertheless the field of enquiry has been somewhat narrowed.

The results of the experiments, which do not have a direct bearing on the possible limiting factors but rather on special aspects of the physiology of the larvae, have been discussed under Tables III, IV and V.

Summary.

1. The larvae of *A. concolor* have been recorded only in coastal rock pools, of salinity varying from 1 gm. of salts to 74 gm. of salts per litre.

2. Breeding takes place mainly from October to April in the Sydney district, while the species overwinters chiefly as fourth instar larvae.

3. The main food of the larvae is organic detritus.

4. Fertile eggs are deposited freely by females which have had no blood feed, but which have fed on fruit juices. These females were developed from larvae fed on a diet rich in both protein and carbohydrate.

5. Copulation takes place readily in small cages and virgin females deposit numbers of non-fertile eggs.

6. Large numbers of adults have been developed from the egg stage in the laboratory, using a powdered " fish food " as the only larval food. This material is composed of oatmeal, wheat-meal, rice flour, dried prawns, dried eggs and meat meal, in a finely powdered condition, and contains 55·6 per cent. carbohydrate, 30·3 per cent. protein, 8·8 per cent. fat and 5·2 per cent. ash.

7. Under laboratory conditions the total life-cycle from egg to egg varies from 28 to 39 days at temperatures of 70°–80°F.

8. Laboratory experiments on the larval environment have been carried out and the methods used in these experiments are described. A standard food (" fish food "), has been used throughout the experiments and has been shown to be essential for the development of the larvae in the waters used.

9. *A. concolor* will develop from egg to adult in any dilution of sea-water plus " fish food," and in tap-water plus " fish food."

10. With a gradual increase in salinity adults of *A. concolor* have been produced from sea-water of a salinity of 180 gm. per litre, while fourth instar larvae will live for 5 days in sea-water containing 200 gm. of salts per litre.

11. Larvae of *A. concolor* will not develop in distilled water plus " fish food," all dying before the first ecdysis.

12. Larvae of *Culex fatigans* will develop from egg to adult in distilled water plus " fish food."

13. *A. concolor* will develop from egg to adult in artificial sea-water prepared from distilled water and pure chemicals, and in distilled water containing a " balanced solution " of NaCl and $CaCl_2$. Larvae will not develop in solutions of

NaCl or $CaCl_2$ used separately. In every case " fish food " had been added to the solutions.

14. Larvae of *A. concolor* will withstand abrupt changes in the salinity of sea-water from $S‰_0 10$ to $S‰_0 105$ and from $S‰_0 105$ to $S‰_0 10$ ($S‰_0$ = total salts per litre). A physiological adaptation takes place in larvae gradually accustomed to increasing salinity.

15. The females oviposit on distilled water in preference to clean filtered sea-water of $S‰_0 35$ and $S‰_0 50$.

16. Some salinity records for other species are given, with notes on the relative sizes of the anal papillae. Anal papillae are vestigial (or rudimentary) in the larvae of *A. concolor.*

17. The results of the field observations and laboratory experiments are discussed from the physiological and ecological aspects.

The author's thanks are due to Professor W. J. Dakin, who first suggested an investigation on the size of the anal papillae of *A. concolor,* and who gave advice on methods of sea-water analysis ; to Mr. F. H. Taylor for checking the identification of various species of mosquitos ; to Messrs. G. Wright and G. J. Burrows for advice on chemical aspects of the work, and to Miss E. Thompson for analysis of " fish food " ; to Miss K. Sawkins for counts of bacteria ; and to Mr. D. J. Lee for certain records of salinity.

References.

BALFOUR, A. (1921). Mosquito breeding in saline waters.—Bull. Ent. Res., **12,** p. 29.

BEATTIE, M. V. F. (1932). The physico-chemical factors of water in relation to mosquito breeding in Trinidad.—Bull. Ent. Res., **23,** pp. 477–496.

BUXTON, P. A. (1934). Further studies upon chemical factors affecting the breeding of *Anopheles* in Trinidad.—Bull. Ent. Res., **25,** pp. 491–494.

COOLING, L. E. (1924). Larval stages and biology of the commoner species of Australian Mosquitos.—Commonw. Austr. Dep. Hlth. Serv. Pub. (Trop. Div.) no. 8.

DAKIN, W. J. & EDMONDS, E. (1931). Regulation of the salt contents of the blood of aquatic animals and the problem of the permeability of the bounding membranes of aquatic invertebrates.—Austr. J. Exp. Biol., **8,** p. 169.

DE VOGEL, W. E. (1907). Atti della Soc. per gli Studi della Malaria, **8,** p. 1.

DE BOISSEZON. (1933). De l'utilisation des protéines et du fer d'origine végétale dans la maturation des oeufs chez *Culex pipiens.*—C. R. Soc. Biol., **114** (31), pp. 487–489.

GIBBINS, E. G. (1932). A note on the relative size of the anal gills of mosquito larvae breeding in salt and fresh water.—Ann. Trop. Med. Parasit., **26,** pp. 551–554.

HAMLYN-HARRIS, R. (1927). Notes on the breeding places of two mosquitos in Queensland.—Bull. Ent. Res., **17,** pp. 411–414.

——. (1928 a). The relation of certain algae to breeding places of mosquitos in Queensland.—Bull. Ent. Res., **18,** pp. 377–389.

——. (1928 b). Notes on the breeding habits of *Culex fatigans* Wied, and its associated mosquitos in Queensland.—Proc. Roy. Soc. Queensland, **40,** pp. 91–103.

——. (1930). The consideration of certain factors as potentialities in mosquito control in Australia.—*Ibid.,* **42,** pp. 86–105.

Hamlin-Harris, R. (1933). Some ecological factors involved in the dispersal of mosquitos in Queensland.—Bull. Ent. Res., **24,** pp. 229–232.

Harvey, H. W. (1928). Biological Chemistry and Physics of Sea Water.—Cambridge University Press.

Hecht, O. (1932). Experimentelle Beiträge zur Biologie der Stechmücken, II.—Z. angew. Ent., **19,** pp. 578–607.

Hill, G. F. (1922). Notes on the habits and distribution of some North Australian Culicidae.—Commonw. Austr. Dep. Hlth. Serv. Pub. no. 21.

Hinman, E. H. (1932 a). The rôle of solutes and colloids in the nutrition of Anopheline larvae.—Amer. J. Trop. Med., **12,** pp. 263–271.

——. (1932 b). The utilization of water colloids and material in solution by aquatic animals with especial reference to mosquito larvae.—Quart. Rev. Biol., **6,** pp. 210–217.

——. (1933). The rôle of bacteria in the nutrition of mosquito larvae—the growth-stimulating factor.—Amer. J. Hyg., **18,** pp. 224–236.

Legendre, J. (1934). Le moustique maritime.—C. R. Acad. Sci., **199,** pp. 1243–1245.

Mackerras, I. M. (1926). Mosquitos of the Sydney District.—Austr. Nat., **6,** pp. 33–42.

MacGregor. (1921). The influence of the hydrogen-ion concentration in the development of mosquito larvae.—Parasitology, **13,** p. 348.

Mathis, M. (1929). Biologie d'un moustique cotier du Var, *Aëdes desbansi* Séguy.—Bull. Soc. Path. exot., **22,** pp. 179–183.

——. (1934). Influence du NaCl sur le déterminisme de la ponte chez un moustique côtier du Var, *Aëdes desbansi* Séguy.—Bull. Soc. Path. exot., **27,** p. 757.

Roubaud, E. (1931). Sur l'autogénese chez *Culex pipiens.*—Bull. Soc. Path. exot., **24,** pp. 384–387.

Roubaud, E. & Treillard, M. (1930). Sur une race physiologique sur-active du moustique commun, *C. pipiens.*—Bull. Soc. Path. exot., **23,** pp. 196–201.

——. (1934). Influence de la nourriture larvaire sur le developpement et le comportement aggressif des anopheles.—Bull. Soc. Path. exot., **27,** pp. 461–467.

Rozeboom, L. E. (1935). Relation of bacteria and bacterial filtrates to the development of mosquito larvae.—Amer. J. Hyg., **21,** 167.

Senior-White, R. (1926). Physical factors in mosquito ecology, Pt. 1.—Bull. Ent. Res., **16,** pp. 187–248.

——. (1928). Physical factors in mosquito ecology, Pt. 2.—Ind. J. Med. Res., **16,** pp. 11–30.

——. (1934). Three years mosquito control work in Calcutta.—Bull. Ent. Res., **25,** p. 551.

Taylor, F. H. (1914). The Culicidae of Australia, 1.—Trans. Ent. Soc. Lond., **1914,** pp. 683–708.

——. (1928). Notes on the life-history and habits of some Australian mosquitos.—Health, **6,** pp. 1–5.

——. (1929). The Anopheles of the Australian Region ; bionomics and distribution.—Trans. Far East Ass. Trop. Med., **3,** pp. 143–163.

——. (1934 a). A check list of the Culicidae of the Australian Region.—Commonw. Austr. Dep. Hlth. Serv. Pub. (Sch. Pub. Hlth. Trop. Med.) no. 1.

TAYLOR, F. A. (1934 b). The Diptera of the Territory of New Guinea, 1.—Proc. Linn. Soc. N.S.W., **57**, pp. 229–236.

TRAGER, W. (1935). The culture of mosquito larvae free from living micro-organisms.—Amer. J. Hyg., **22**, pp. 18–25.

VOGEL, R. (1927). Int. Rev. ges. Hydrobiol. u. Hydrog. **17**, p. 355.

WIGGLESWORTH, V. B. (1930). A theory of tracheal respiration in insects.—Proc. Roy. Soc. Lond. (B), **106**, p. 229.

——. (1933 a). The effect of salts on the anal gills of mosquito larvae.—J. Exp. Biol., **10**, pp. 1–15.

——, (1933 b). The function of the anal gills of the mosquito larva.—J. Exp. Biol., **10**, pp. 16–26.

——. (1933 c). The adaptation of mosquito larvae to salt water.—J. Exp. Biol., **10**, pp. 17–27.

A METHOD OF TESTING OILS AND OTHER CHEMICAL AGENTS FOR KILLING MOSQUITO LARVAE.

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In 1933, the late Dr. Drysdale Anderson made a series of laboratory experiments at Onitsha, Southern Nigeria, to study the mosquito larva-killing properties of a number of mineral oils and of some mixtures of these oils. For the experiments he used fresh fourth instar larvae of *Anopheles costalis,* Giles, which is the most common malaria-carrying species in Nigeria ; these larvae he obtained from two temporary pools in the bush, which produced large numbers of larvae in wet weather but dried up after a period of 48 hours without rain.

For his experiments Dr. Anderson used plates marked at a diameter of 19·5 cm. (giving a depth of fluid of 2·5 cm.) with 20 to 30 larvae for each plate and one observer for every 3 plates. An experiment consisted of an average of 200 larvae. The oil was applied by discharging 0·65 cc. from a pipette.

It was suggested that confirmatory experiments in the field were required to check the results of these laboratory experiments. This led to the methods described below being devised by us for testing the efficiency of larvicides under conditions as nearly natural as practicable.

To ensure comparability of results we dug our own breeding-pits, each approximately 2 feet by 2 feet square, on low-lying ground where the ground water is very near the surface. The pits were made of such a depth as to contain 8–12 inches of water and are kept under observation for breeding, and when this occurs its intensity is recorded by measuring out a definite number of dips taken along the four sides of the pit and by counting the larvae captured.

For this " dipping " we made our own rectangular dishes of zinc sheeting with sloping sides 2 inches from rim to bottom, 9 inches by 5½ inches in area at rim level, and 8 inches by 4½ inches in area at the bottom. In practice, such dishes collect about 30 fluid ounces at each complete dip.

The dipping was done in horizontal sweeps along each side of each pit—one side, one sweep, one trayful. Dealing with the same pit, time was allowed after each dip for the disturbed water and contained larvae to settle before another side was swept. When testing several pits simultaneously, first one, say the north, side of each pit was swept, so that by the time the first dip had been made along one side of the last pit, the first pit had settled and was ready for a second dip to be made along another of its sides. In working with various pits, each pit was numbered on a peg stuck by its side in the adjoining ground. No pit in our experiments was used for more than one test, and a separate set of containers was used for each test performed on the same day.

The four trayfuls (one from along each of the four sides of each pit) were transferred into one large container. We used large, cylindrical, shallow glasses which we happened to have available ; but ordinary enamelled iron basins should prove equally suitable.

The counting was done by picking the larvae out of the large container with a pipette, transferring each larva to another container and, on completion of the count, returning the larva-containing sample to the pit from which it had originally been recovered. The larvae were roughly classified during each count into Culicines and Anophelines.

Preliminary tests with varying quantities of a known larvicidal oil showed that 5 cc. was a good uniform amount to use for these areas of 4 square feet of water provided by our experimental pits, and this amount has been adopted for our comparative studies of the efficiency of liquid mosquito larvicides. The 5 cc. of larvicide is measured out into a graduated cylinder and left to settle, so as to minimise error due to oil remaining over too large an area of the sides of the cylinder. When the count has been made and the sample has been returned to the pit from which it had been taken, the measured quantity of oil is poured out of the cylinder gently on the surface of the water in the pit, starting from the centre and moving spirally and centrifugally towards the periphery. This ensures as uniform a distribution of film as possible.

The checking of the larvicidal effect of the fluid being tested was made by dipping and counting as described above at various intervals after the oiling. Ten oils were studied by this method ; of these, four were different brands of kerosene, one was a gas oil of a medium grade, two were fuel oils of a medium grade, one was a fuel oil of a heavy grade, one was a special " anti-malaria " oil, and one was a modification of the latter containing less medium and more heavy oil. To illustrate the working of our method, the records of two of our experiments are given below and on p. 651. The time is recorded on the 24-hour system and abbreviations are used to record the findings ; ala = anopheline larvae alive, cla = culicine larvae alive, ld = larvae dead, pa = pupae alive, and pd = pupae dead.

Oil No. 3 is a well-known kerosene and Oil No. 10 is a Diesel oil of which large quantities are used for larvicidal work in Lagos. Considering the frequency with which the use of (undefined) kerosene is recommended as a mosquito larvicide and the expenditure incurred on supplying kerosene for such use in the past, the value of our method of testing larvicides is obvious.

The method, however, is somewhat laborious and rather inconvenient in practice, especially in these days of much reduced staff and much increased work, at any rate in the case of some colonies. To overcome such disadvantages a simpler, and perhaps even more reliable, modification of the method has now been adopted. The making of the pits, the ascertaining of their breeding capacity by standard counting, and the application of the larvicide to be tested follow the procedure already described. The efficiency of the larvicidal action, however, is not gauged by further laborious dipping and counting, but by searching for emerged adults, the possibility of fresh breeding after the application of the larvicide being excluded by covering over the pit with a specially made trap.

Oil No. 3. *Experiment* 12. *Pit* No. 18.

Date	Time	Observations
9.10.34	0700	4 dips, 30 ala, 98 cla.
	0745	5 cc. of oil No. 3 added ; very slow spread without forming a complete film.
	1000	4 dips, 15 ala, 40 cla.
	1300	4 dips, 15 ala, 21 cla. No evidence of film to be seen. Several fully grown dead larvae seen in pit water.
10.10.34	0900	4 dips, 7 ala, 15 cla. Fully grown.
	1000	4 dips, 6 ala, 12 cla.
11.10.34	0930	4 dips, 12 ala, 9 cla, 3 pa.
12.10.34	0830	4 dips, 8 ala, 4 pa.
13.10.34	1030	4 dips, 18 ala, 11 cla.
14.10.34		Considerable breeding. Pit closed.

Oil No. 10. *Experiment* 7. *Pit No.* 12.

Date	Time	Observations
26.9.34	0700	4 dips, 507 ala, 71 cla, 7 pa.
	0730	5 cc. of oil No. 10 applied ; immediate spread forming good, even, complete film. Larvae can be seen struggling at the surface of the water, obviously in distress.
	0800	Larvae very sluggish.
	0840	4 dips, 5 ala, 10 cla, 35 ld., 4 pd.
	1100	4 dips, no larvae or pupae seen. Apparently a complete kill.
	1345	4 dips. No larvae or pupae seen.
27.9.34	0815	4 dips. No larvae or pupae seen. Film thin, but complete.
28.9.34	0748	4 dips, 8 ala, 1st instar. No signs of oil.
	1300	4 dips, 5 ala.
29.9.34	0815	4 dips, 25 ala.
30.9.34	0930	4 dips, 65 ala, 20 cla.
1.10.34	0830	4 dips, 60 ala, 10 cla.
2.10.34	0820	4 dips, 110 ala, 2 cla.
3.10.34	0900	4 dips, 65 ala.
4.10.34	0845	4 dips, 37 ala, 1 cla, 1 pa.
5.10.34		4 dips, 28 ala.
6.10.34		2 dips, 10 ala, 2 cla, 2 pa.
7.10.34	1330	4 dips, 18 ala, 6 cla.
8.10.34	1400	4 dips, 20 ala, 5 cla.
9.10.34	1100	4 dips, 92 ala.
10.10.34	1315	4 dips, 28 ala.
11.10.34	1045	4 dips, 95 ala, 3rd instar
12.10.34	1055	4 dips, 78 ala.
13.10.34	1030	4 dips, 84 ala, 2 pa.
14.10.34	1200	4 dips, 65 ala, 2 pa.
		Pit closed.

These cover-traps are constructed of ½-in. board and have a pyramidal shape. The pyramid has a truncated apex so that each of its four sides is a trapezoid measuring 3 ft. at the base, 6 ins. at the top and 3 ft. 3 ins. along each side edge. With such a base of 3 ft. by 3 ft. the cover-traps have ample overlap when fitted over our 2 ft. by 2 ft. pits. On the truncated apex is fitted a mosquito trap which is a modification of a type described by Le Prince and Orenstein. The cover and the trap communicate through a circular opening 4 ins. in diameter. Over this opening two glass strips are fixed so as to form the sides of a horizontal wedge-shaped space, the base of which is formed by the wooden base of the trap (opening into the pyramidal cover). The trap chamber is an incomplete horizontally-placed cylinder with wooden ends, its round side being formed of wire mosquito-gauze for about three-quarters of the circumference, the rest of the circumference being replaced by the flat wooden base of the trap. The two sloping glass strips are separated by an interval of ¼ in. along their upper edges, and the slit so left is the only means whereby mosquitos hatching in the pit can find their way upwards into the trap, where they are seen by the observer through the wire gauze. Each pyramidal cover is fitted with a rectangular window 8 ins. by 7 ins. on each of its four sides ; two of these windows are of glass to facilitate inspection of the pit without removal of the cover, the other two windows on each cover are closed with perforated zinc sheeting to help keep the atmosphere under the cover sufficiently ventilated. The wooden covers are painted white inside and outside to help reduce any tendency to excessive heating from the effect of the sun.

The records of two of our tests are given below as an illustration of the modified method last described :—

Oil No. 3. *Experiment* 36.

Date	Observations
9.2.35	4 dips, 117 ala, 12 cla, 3 pa. 5 cc. of oil No. 3 applied and pit covered.
10.2.35	Breeding in pit very marked.
11.2.35	Breeding continues with pupation. 3 adults observed.
19.2.35	Larvae and adults have been noticed daily.
20.2.35	No more larvae noticed. Many adults appear to be daily eaten by ants.
22.2.35	Experiment discontinued.

Oil No. 10. *Experiment* 29.

Date	Observations
30.12.34	4 dips, 65 ala, 45 cla, 1 pa. 5 cc. of oil No. 10, with crude castor oil 1 : 140, applied and the special mosquito cover-trap fitted.
13.1.35	No mosquitoes seen in trap on any day. Pit closed.

Over laboratory experiments, the methods devised by us have the advantage of enabling the test to be conducted under conditions as nearly natural as possible. The advantage of our methods over ordinary field tests lies in the fact that reliable comparative results are rendered possible by the adoption of standard uniform conditions—area of breeding water, quantity of larvicide, &c.—for each test.

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ON THE RELATION OF *PHLEBOTOMUS PAPATASII* TO THE TEMPERATURE AND HUMIDITY OF THE ENVIRONMENT.

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The bionomics of sandflies (*Phlebotomus* : Psychodidae) have been studied mainly in relation to the diseases they transmit. Comparatively little experimental work has yet been undertaken on the physiology of *Phlebotomus* in the laboratory. In the present paper experiments are described on the thermal limits of *Phlebotomus*, on the influence of temperature and humidity on the length of life of adult sandflies and on the loss of water in larvae and pupae. The problem of loss of water in sandflies is of particular interest, since adjustment to a varying humidity under natural conditions appears to be an important factor in the transmission of diseases by these insects.

For the study of sandflies in the laboratory an ample supply of insects raised under uniform conditions is required. In a previous publication (1934) a breeding method has been described which provides any desired number of sandflies. If overcrowding of the breeding pots is prevented the flies are relatively uniform.

The species used in the experiments was *Phlebotomus papatasii*, the common sandfly of the Mediterranean, which is the most suitable species for laboratory work ; it is comparatively easy to breed and to handle and feeds readily in captivity. The sandflies used in the experiments were bred from females caught in October in Jerusalem. The pots containing the larvae were wrapped in moist cottonwool and survived the transport to London without any damage. The work was commenced, and parts of it completed, in the Department of Entomology, London School of Hygiene and Tropical Medicine, where I held the Avebury Studentship. It is a pleasure to acknowledge the help received from Professor P. A. Buxton and the valuable collaboration of Mr. J. D. Gillett. The work was completed in Jerusalem.

Effect of Blood Meal on Weight of Phlebotomus.

Phlebotomus papatasii is 2·5–2·8 mm. in length. Immediately after hatching a female weighs 0·5–0·6 mg. It loses weight rapidly by excreting fluid during the first few hours, and then more gradually according to the temperature and humidity in which it is kept, *e.g.*, at 23°C. and a relative humidity of 95 per cent. *circ.* female sandflies lost 0·06–0·08 mg. on the first day and 0·04–0·05 mg. on the second to fourth day. The average weight of a female *P. papatasii* on the third day of starving was 0·35–0·4 mg. Males weighed less. Immediately after hatching they weighed 0·45–0·5 mg. and on the third day of their life they weighed on an average 0·24–0·28 mg.

In order to study the change of weight after feeding the insects were kept singly in test-tubes with a cottonwool plug, and a drop of water was put on the wool every day. For weighing, the sandfly was narcotised by placing a few drops of ether on the cottonwool and removed from the tube as soon as it was motionless. The narcosis lasts from 1 to 2 minutes and apparently does no harm to the sandfly. At 23°C. they lived up to 20 days, being etherised during that time up to 20 times. On feeding days they were etherised twice, once for the weighing before the feed and once immediately after the feed. They generally fed within one hour (sometimes within 15 minutes) after recovering from the narcosis. Sandflies kept as a control under the same conditions and fed at equal intervals did not live longer than the etherised ones. The amount of blood taken was 0·4–0·5 mg. as a rule at the first meal. The heaviest meal observed was 0·58 mg. No proportion was found between size or weight of the sandfly and the amount of blood taken, *e.g.*, a meal of 0·57 mg. was taken by a sandfly (5 days old) weighing 0·26 mg., and a meal of 0·58 mg. was taken by a sandfly (1 day old) weighing 0·48 mg.

The second meal was usually taken after 3 days at 23°C. and 2–3 days at 30°C. and was smaller as a rule (0·25–0·35 mg.). The third to sixth meals were on an average 0·15–0·20 mg., rarely up to 0·25 mg. Only in two cases was the fourth meal heavier than the preceding one.

At 30°C. the amount of the first meal was about the same as at 23°C., but the second meal was smaller, only 0·15–0·2 mg. on an average, and most sandflies died after the second meal.

TABLE I.

Weight of Blood Meals of Phlebotomus papatasii *in mg.*

	Meal No.	Sandfly No.							
		1	2	3	4	5	6	7	8
23°C.	1	0·44	0·26	0·57	0·38	0·54	0·20	0·27	0·43
	2	0·29	0·29	0·38	0·33	0·24	0·25	0·20	0·22
	3	0·23	0·15	0·16	0·16	0·20	0·10	0·11	0·19
	4	0·23	0·11	0·28		0·17	0·15	0·23	
	5	0·07	0·12			0·15	0·02	0·17	
	Meal No.	Sandfly No.							
		9	10	11	12	13	14	15	16
30°C.	1	0·36	0·58	0·37	0·42	0·43	0·36	0·37	0·42
	2	0·21	0·13	0·21	0·12	0·09	0·18	0·12	0·21
	3	0·25		0·14					

Fig. 1 shows a typical curve of weight at 23°C. and at 30°C. Three different stages may be distinguished in the interval between two feeds. On the first day the loss of weight is relatively great, clear fluid is excreted from the anus, and one-half to two-thirds of the weight gained by the feed is lost. During the next few days the loss of weight becomes gradually smaller as digestion proceeds. If the sandfly is starved after all the food is digested the loss of weight becomes again more rapid and uniform, and the body reserves appear to be utilised as in the unfed sandfly. The development of eggs does not increase the body weight to any considerable extent. Some sandflies weighed about the same before the first feed as after the fifth feed with fully developed eggs. Since the sandflies were not allowed to starve to the extreme limit between feeds, the weight of the sandfly immediately before the later feeds was usually higher than at the commencement of the experiment.

At 30°C. the loss of weight during the day after the first feed was still more marked than at 23°C. ; *e.g.*, a sandfly having gained 0·58 mg. lost 0·41 mg. in one day, another having taken 0·42 mg. of blood lost 0·32 mg. in one day, *i.e.*, about 75 per cent. of the weight gained by the feed. Otherwise the curves were similar to those obtained at 23°C.

The excretion of clear fluid sometimes started during the feed, or immediately afterwards, and it was observed mainly in the first two feeds. There was apparently no need to get rid of the superfluous fluid in the later, relatively smaller feeds.

Experiments of the loss of water of adult sandflies under controlled conditions of humidity and temperature are in progress.

Sandflies do not drink water under normal circumstances. Their alimentary tract is sterile and the bacterial contamination usually contracted by drinking water invariably kills them in a short time.

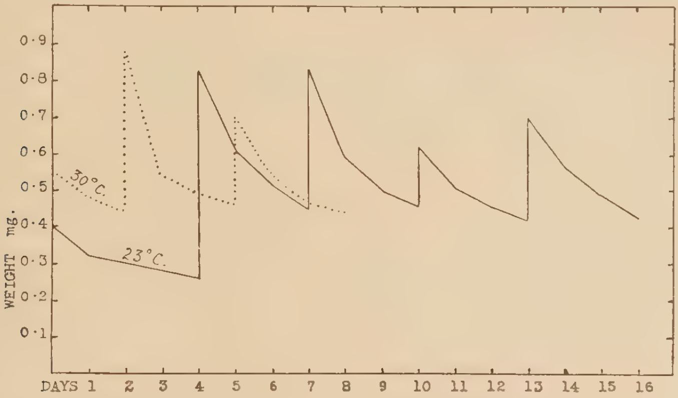

Fig. 1. Change in weight of fed *Phlebotomus papatasii* at 23°C. and 30°C.

Relation of P. papatasii to Temperature in Nature.

At a temperature of 30°C. the whole cycle of development from egg to egg takes about 36 days, but under the conditions generally prevailing in the Mediterranean, and particularly in the microclimate in which the sandflies live, the mean temperature is much lower. In Jerusalem, for instance, at a temperature from 21 to 24°C. only one generation reaches the adult stage in summer, and the larvae of this generation go into hibernation and hatch in May of the following year.

Upper Thermal Limits of P. papatasii.

As sandflies are mainly inhabitants of temperate and hot climates they might be expected to withstand rather high temperatures but not very low temperatures. The following experiments were carried out to determine the thermal limits of *P. papatasii*.

Sandflies were taken from the breeding pots once a day, so that their age at the beginning of the experiment was up to 30 hours throughout. For experiments with fed flies females were allowed to gorge themselves once on the first day of their life. About 80 per cent. of normally developed sandflies were ready to feed 24 hours after hatching.

In determining the upper thermal limit, or thermal death point, an apparatus described by Buxton (1931) and Mellanby (1932) was used. It consists of a copper tank with water kept at a constant temperature by electric heating and a thermo-regulator. The water is stirred by a stream of compressed air and the temperature is recorded by a distance thermograph. The sandflies are kept in small glass tubes closed at both ends with fine gauze. These tubes are suspended from a wire in a larger tube containing sulphuric acid-water mixtures, giving the desired relative humidities. In one of the tubes a thermometer is kept in place of the sandflies. Several tubes and the tube containing the thermometer are fixed in a meccano frame, so that a whole set of experiments at different relative humidities is carried out simultaneously. The whole apparatus is kept completely submerged in the heated tank for 1, 2, 6 and 24 hours respectively. At each temperature experiments at relative humidities of 40, 60, 80, 90, 95 and 100 per cent. R.H. were put up, 10 to 20 sandflies of both sexes being used for every combination of temperature and humidity.

Unfed adult sandflies.

One hour's exposure.—Unfed females died at 40·5°C. at all humidities. All males were alive at this temperature. At 41·5° the majority and at 42° all males were dead (fig. 2).

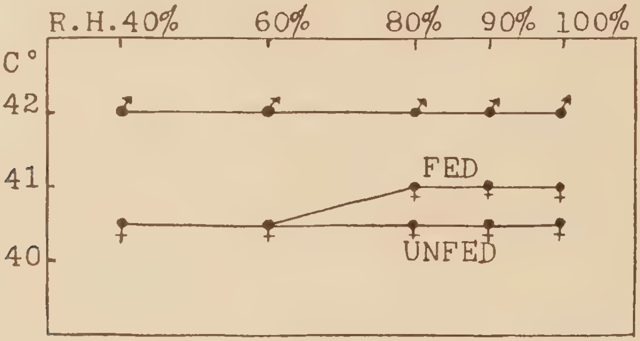

Fig. 2. Thermal death point of *P. papatasii* at one hour's exposure.

Two hours' exposure.—At all humidities most females died at 40°C. and most males at 40·5°C.; no male survived 41° and no female 40·5°. At 39·5° all males and 70 per cent. of the females survived.

Six hours' exposure.—In relative humidities up to 80 per cent. the majority of the females died at 39·5°C. and all males survived. In humidities of 90 to 95 per cent. half of the females and all males survived. At 40·5° all sandflies of both sexes died at all humidities.

Twenty-four hours' exposure.—In these experiments the influence of humidity was more strongly marked. At R.H. 40–60 per cent., 50–80 per cent. of the flies died even at 35°C. At 38° the majority of the females and 75 per cent. of the males died in humidities from 60–80 per cent. and 50 per cent. of the flies survived only at 90–95 per cent. R.H. At 39·5° all sandflies died at all humidities (fig. 3).

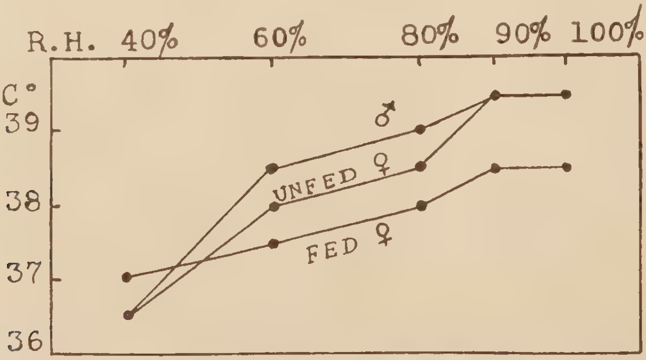

Fig. 3. Thermal death point of *P. papatasii*, 24 hours' exposure.

Fed females.

The results of the experiments at an exposure of one and two hours were similar to those obtained for unfed flies, except that 25–40 per cent. of the females survived one hour at 40·5°C. in 80–95 per cent. R.H.

After 6 hours the majority had died at 38·5° (a temperature which all unfed sandflies survived for 6 hours), and only a few survived 39·5°.

After 24 hours at 38·5° all fed flies died at all humidities. At 37·5° nearly all died at relative humidities of 40–80 per cent., but nearly all survived 24 hours in the high humidities (90 and 95 per cent.) (fig. 3).

It seems, therefore, that males were able to resist a higher temperature than females for short exposures at all humidities, and fed females died at a lower temperature than unfed ones after an exposure of 24 hours. The influence of humidity on survival was only slightly apparent after 6 hours, but was much more marked after an exposure of 24 hours, following which the number of survivors gradually increased with the higher humidity. The fact that fed females die at a lower temperature than unfed ones at long exposures is difficult to explain, particularly in the light of experiments of Mellanby with lice and mosquitoes (1934). In his experiments fed insects survived temperatures 2°–3°C. higher than unfed ones. He has pointed out that several factors act together in determining the thermal death-point of an insect, viz., heat, desiccation and starvation, and he regards the death of unfed lice at lower temperatures than those at which fed insects die as being due to starvation. The results recorded above for unfed sandflies at long and short exposures are in accord with his interpretation of the action of heat and desiccation. It seems however impossible to explain the death of fed sandflies at relatively lower temperatures as being due to starvation, and the matter is apparently more complicated in sandflies. No explanation for this phenomenon can be given at present and the matter requires further investigation.

Effects of Desiccation on Larvae.

Sandfly larvae are extremely sensitive to desiccation ; they die at all humidities in a few hours, and survive for longer periods only if they are in the presence of fluid water or in saturated air where droplets of condensation are usually present. (This question will be dealt with later.) Experiments were therefore arranged only at R.H. 85, 90, 95 and 100 per cent. (In the tubes with 100 per cent. R.H. condensation of water occurred frequently.) About 10 per cent. of the larvae survived one hour's exposure at 41·5°C. and all died at 42° in all humidities. At 40·5°, 50 per cent. of the larvae died at 85 and 90 per cent. R.H. and all survived in 95 and 100 per cent. R.H. At 39·5° half of the larvae died at 85 per cent. R.H. and in the higher humidities all survived.

After 3 hours all were dead at 41·5°C. in all humidities ; at 40·5°, 50 per cent. of the larvae died at 95 and 100 per cent. R.H. and all died at 85 and 90 per cent. R.H. ; at 39·5° all survived at 100 per cent. R.H., 50 per cent died at 90 and 95 per cent. R.H., and all died at 85 per cent. R.H. At 38·5°, 50 per cent. of the larvae died at 85 and 90 per cent. R.H., and all survived at 95 and 100 per cent. R.H., and at 37·5°C. all survived except in 85 per cent. R.H. where 50 per cent. of the larvae died.

After 6 hours' exposure all died at 37·5° in all humidities, and at 36·5° they survived at 95 and 100 per cent. R.H. but died in lower humidities.

After 24 hours all were dead at 36·5°, and at 35·5° all survived at 100 per cent. R.H. (condensation water) but all died at all other humidities (fig. 4).

It is obvious that heat alone killed the larvae in the experiments with short exposure and at humidities of 95 and 100 per cent. R.H., and that desiccation begins to act even after only one hour's exposure at 85 and 90 per cent. R.H. and in ever increasing measure in the longer exposures. The lethal temperature for the larvae is exactly the same as for male sandflies.

The above experiments emphasize the importance of a study of the exact conditions of the sandfly's environment in nature. The climatic conditions in caves, deep cracks in walls or dark corners in houses, where sandflies usually hide during the day, will even in hot climates very rarely attain values unfavourable to sandflies, and the lower temperature and increased humidity at night provide tolerable conditions for sandflies even in the hottest and driest climates. It is very desirable that observations of the type made by Buxton (1932, a and b) on temperature and humidity in caves, rat-holes and cracks in walls should be extended, particularly if more refined methods can be devised.

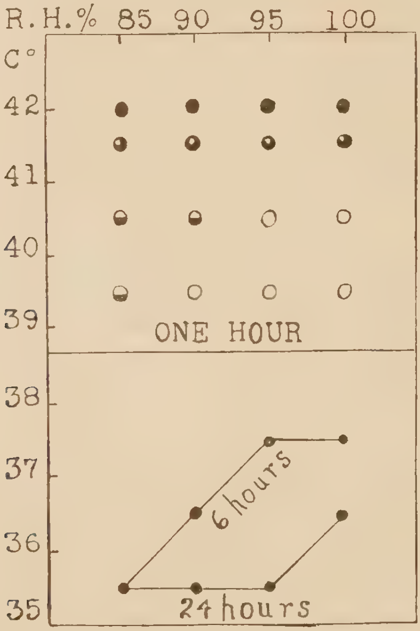

Fig. 4. Thermal death point of larvae of *P. papatasii*. Black circle indicates that all died, a white one that all survived. Partly blackened circle indicates percentage of larvae dying.

Lower Thermal Limit.

In the Mediterranean, sandflies disappear with the onset of the winter rains and hibernate as fourth stage larvae in the soil or in cracks in walls, *i.e.*, in places more or less protected against low temperatures.

Sokolow & Tarvit (1936), in Tashkent, found that an exposure for 6 minutes at – 8°C. and an exposure of 30 minutes at – 7° killed adult sandflies. Cold paralysis started at + 10° in their experiments.

The few experiments carried out with low temperatures gave similar results. Cold paralysis started at 10°C., and the sandflies remained alive in this state up to 19 days at humidities of 80 per cent. and more. At 6° their span of life was considerably shorter. Thus temperatures under 10° may be considered as definitely unfavourable for adult *P. papatasii*.

Larvae died after 4½ days at 0° and in 2–3 days at –2°C. At –6° they died in 2½ hours, and at –10° all were dead after half an hour's exposure.

Patton & Hindle (1928) in China found that one night's exposure to –11°C. killed all larvae of *P. sergenti* and *P. chinensis*, but that they were able to survive any length of time at 0°C.

In nature hibernating larvae of *P. papatasii* and *P. perniciosus* survive a temperature of + 3·4°C. (Sicily).

These scanty figures show that larvae of *P. papatasii* are able to stand lower temperatures than adults but that they will not be able to exist in countries with strong and persistent frosts, although they live in relatively sheltered places. Other species of sandflies may of course be able to stand lower temperatures than *P. papatasii,* as the results of Patton and Hindle show.

TABLE II.

Adult sandflies died		Larvae died	
at +6°C.	In 6 to 8 days		
+3°C.	,, 4 days		
0°C.	,, 2 to 2½ days		4½ days
−2°C.	,, 12 hours		2 to 3 days
−4°C.	,, 3 ,,	−6°C.	2½ hours
5·5°C.	,, 2 ,,	−10°C	½ hour
−7°C.	in 30 minutes	After Sokolow and Tarvit	
−8°C.	,, 6 ,,		

Survival of Adult Sandflies at different Combinations of Humidity and Temperature.

In nature sandflies enter houses for feeding, and some species (*e.g., P. papatasii*) remain there for several days, although the percentage of females with digested blood and well developed eggs among those found in houses is comparatively low. Others (*e.g., P. perniciosus*) disappear immediately after feeding and go into hiding. Some species (*e.g., P. papatasii*) feed several times before egg-laying, while others (*e.g. P. perniciosus*) feed only once, but take sufficient for the development of a batch of eggs. As sandflies do not drink under natural conditions their only source of water is blood, so that if a sandfly of the second type were to lose water easily it could not replace it. This may explain the relatively rapid disappearance of species like *P. perniciosus* from its feeding-places into its hiding-places, where evaporation is certainly less than in the open. A study of the resistance to desiccation of different species of sandflies might therefore enable us to explain their behaviour.

From 10 to 20 sandflies were placed in tubes closed with gauze and kept in vessels with the appropriate mixtures of sulphuric acid and water which were kept in constant temperature rooms. All sandflies used for these experiments were up to 30 hours old.

Unfed sandflies.—The figures given in Table III show that at all temperatures the unfed insects live longer at higher humidities. If one takes the mean length of life, it may be shown that it is roughly proportional to the saturation deficiency at 10, 15 and 23°C. and over the wide range of humidities which were studied. But this relatively simple relation to saturation deficiency does not hold good at 30°C., at which temperature the length of life is always much shorter than it is at the same saturation deficiency and a lower temperature. At all temperatures the survival curves show an abrupt and straight course in the low humidities, the time until the first deaths becoming gradually shorter with the rise in temperature. In the high humidities the deaths were distributed over a longer interval (8–10 days) and there were generally a few sandflies living considerably longer than the majority. This is probably due to the different state of nutrition of the larvae and the amount of food reserve passed on by larva and pupa to the adult. In the low humidities loss of water is so rapid that the using up of the food reserves is made impossible and loss of water is clearly the only cause of death, while in the higher humidities starvation and loss of water together determine the length of life.

Fed sandflies.—All females used for these experiments were fed once on their first day. The curves show a much longer interval up to the occurrence of the first deaths than in unfed sandflies. The curves for 30°C. and 23°C. show a sharp and well defined limit of the length of life also in the high humidities. In most experiments all sandflies died within 1 to 2 days at 30°C. and 2 to 3 days at 23°. At 15° digestion is so much reduced that in the high humidities the curves for fed flies resemble those of unfed flies at the same humidities, the deaths being distributed over an interval of 7 to 9 days. About 20 per cent. of the unfed flies at 15° and about 40 per cent. of the fed flies live for 14 days at 95° per cent. R.H.

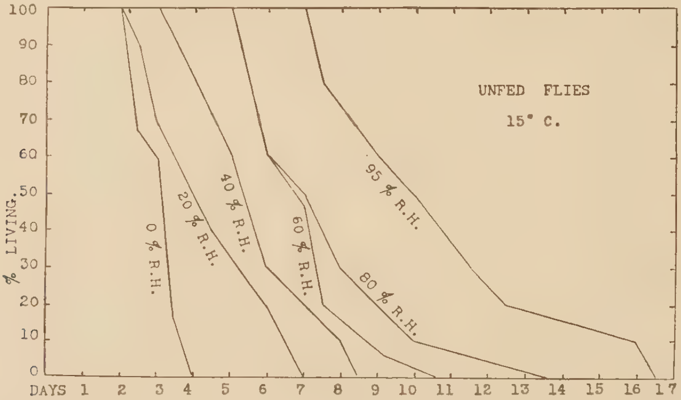

Fig. 5. Length of life of unfed *P. papatasii* at 15°C. and different humidities.

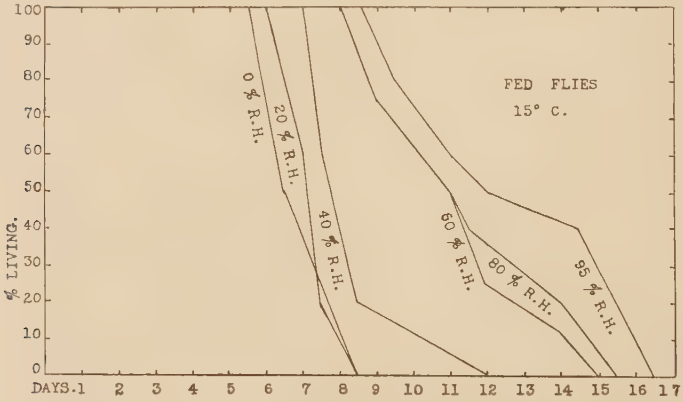

Fig. 6. Length of life of fed *P. papatasii* at 15°C. and different humidities.

Loss of water is compensated for a few days by the ingested blood and then becomes fatal in the low humidities. In the higher humidities death occurs after the food reserves are exhausted (figs. 5, 6, 7 and 8).

The average length of life in fed and unfed flies seems to be not very different at high humidities, *e.g.*, at 30° most fed flies died in 4 to 5 days. The same occurred in unfed flies except in 95 per cent. R.H., where 40 per cent. of the flies lived for 6 days. At 23° the majority of unfed flies died in 6 to 7 days, while the fed ones lived for 8 to 9 days at the higher humidities (Table III).

TABLE III.

Length of Life of unfed and fed Sandflies in Days.

Temp. °C.		Length of life	Relative humidity per cent.								
			100	95	90	80	60	40	20	10	0
10	Unfed flies	Mean			11	8	7·4				4·7
		Extreme			19	11·5	10·5				8
15	Unfed	Mean		11·8	8·5	7·6	7	5·6		4·8	3·25
		Extreme		16·5	15	13	10·5	8·5		7	4
	Fed	Mean		12·1	11	11	11·5	8·1			7·1
		Extreme		16·5	15	15·5	15	12·5			8·5
23	Unfed	Mean			6·7	5·5	5	4			3
		Extreme			12	9·5	8	5			4
	Fed	Mean	9	8·5	7·6	7·5	7·5	5·5	5		3·7
		Extreme	10·5	10	9·5	9	9	7·5	6		4·5
30	Unfed	Mean		6·5	4·1	3·6	3·15	1·6			1·6
		Extreme		9	7	6·5	4	2·5			2·5
	Fed	Mean			5	4·3	4·5	3·5			2·8
		Extreme			6	5·5	4·5	4·5			3·5

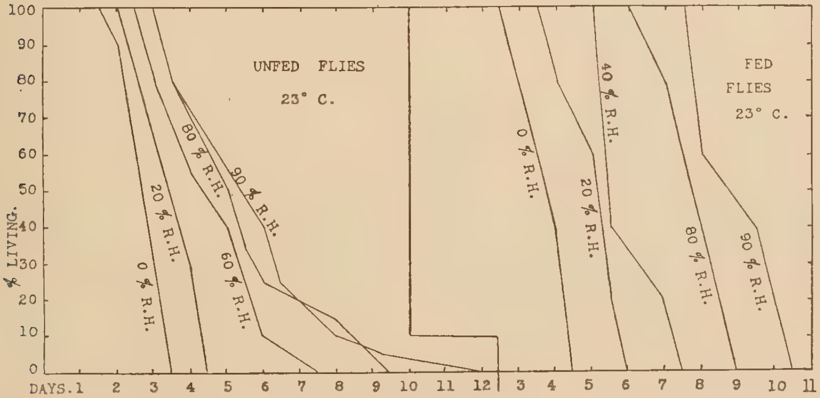

Fig. 7. Length of life of unfed and fed *P. papatasii* at 23°C. and different humidities.

Metabolic processes and the development of the eggs are stimulated by the blood meal. The whole nutritional state of the fed sandfly and its " rate of living " (Pearl) are made uniform, and any possible individual differences in the state of nutrition of the unfed sandfly are compensated. This probably accounts for the clearly defined limit in the longevity of the fed sandflies.

It seems, therefore, that in the low humidities loss of water is the most important factor determining the length of life of sandflies. In the high humidities starvation and loss of water act together.

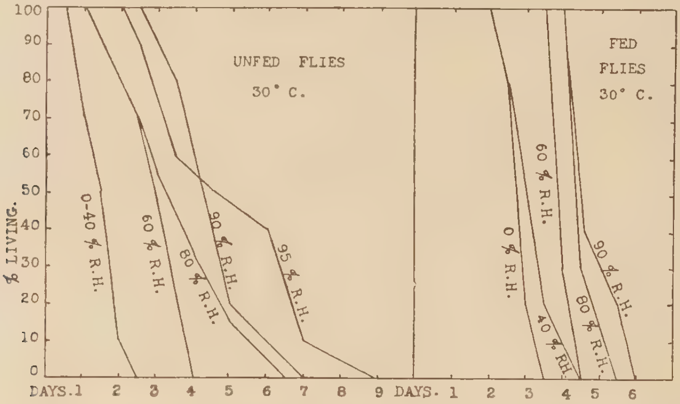

Fig. 8. Length of life of unfed and fed *P. papatasii* at 30°C. and different humidities.

Loss of Water from Larvae and Pupae.

In the experiments on the thermal limit the extreme sensitiveness of larvae to desiccation was noted. The following experiments were undertaken to establish the rate of loss of water from larvae and pupae and the site of loss of water in the larva.

Larvae and pupae were introduced into small glass tubes, kept in larger tubes which contained the sulphuric acid and water mixtures giving the desired relative

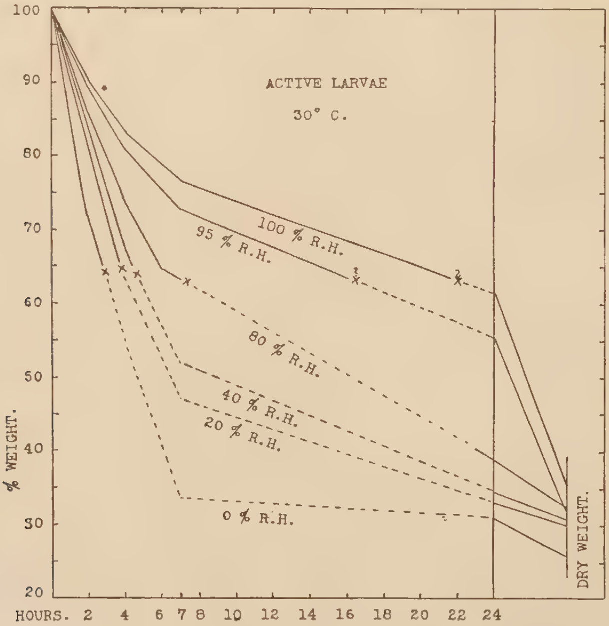

Fig. 9. Rate of loss of water in active larvae of *P. papatasii* at 30°C. and different humidities. A cross indicates approximate time of death.

humidities. A set of experiments at R.H. 0, 40, 80 and 100 per cent., in some experiments also 20, 60 and 90 per cent. were arranged simultaneously for each temperature.

A special torsion balance constructed by Messrs. Oertling & Co., London, with a range of 5 mg. and weighing to 0·01 mg., was used. This balance is extremely delicate and several weighings (three as a rule) were carried out in every case and the average taken.

The larvae were weighed in batches of five at the beginning of the experiment, and again after 2, 4, 6, 8 and 24 hours. For every combination of temperature and humidity 15 to 20 individuals, all of them full-grown fourth stage larvae weighing from 0·6 to 0·8 mg., were used. A certain amount of inaccuracy in the weighing is caused by the adhering of particles of faeces and dust from the breeding pots to the adhesive surface of the larvae. Larvae were examined during the active development in summer (June to November) and during hibernation in December and January.

Active larvae lost nearly all their water in the first six hours in the low humidities (fig. 9). In the higher humidities (R.H. 80 per cent. and above) loss of water is more gradual. The rate of loss of water is practically identical at 23° and 30°C.

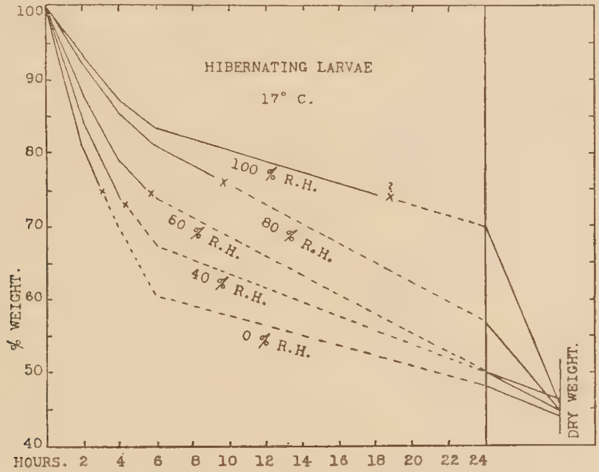

Fig. 10. Rate of loss of water in hibernating larvae of *P. papatasii* at 17°C. and different humidities.

It is difficult to determine exactly the moment of death, as after a short stage of excitation the larvae are motionless some time before death. But experience showed that larvae shrunk to a certain extent did not recover if brought into contact with water. The time of death could therefore only be established approximately by noting at the time of weighing whether the larvae were moving actively, or had become rigid and shrunken.

In this way it was found that active larvae died approximately between 2 and 4 hours at 0 per cent. R.H., 4–6 hours at 20 to 60 per cent. R.H., 6–24 hours at 80 to 100 per cent. R.H. These periods are approximately true at 17, 23 and 30°C. A cross is inserted in the graphs at the approximate time of death and the curve is continued in a broken line. The weighings are continued up to 24 hours in order to see whether the rate of loss of water in the living and in the dead insect were different and whether it would thus be possible to establish the time of death more accurately. The living larva, however, has apparently no mechanism for controlling the exchange of water which continues at an unchanged rate after death. As a control, and in order to find out whether a difference in the rate of loss of water exists between living and dead larvae, some larvae were killed by potassium cyanide. The rate of loss of water was identical in living and dead larvae at least for the first few hours after death.

Dry weight.—After 24 hours the larvae were dried at 105°C. for one hour and weighed. The dry weight was 30 to 35 per cent. of the weight of the larvae at the beginning of the experiment. The lines in the graphs continued after 24 hours indicate the dry weight of that particular batch. The variation in weight is partly due to dust particles which cannot be removed completely without damaging the larvae.

Hibernating larvae.—Some curves are very similar to those of the active larvae, but in others the rate of loss of water is slower (figs. 10 and 11). The dry weight of hibernating larvae is much higher than in active ones (44 to 48 per cent.). This is due mainly to an accumulation of fat, as will be shown later.

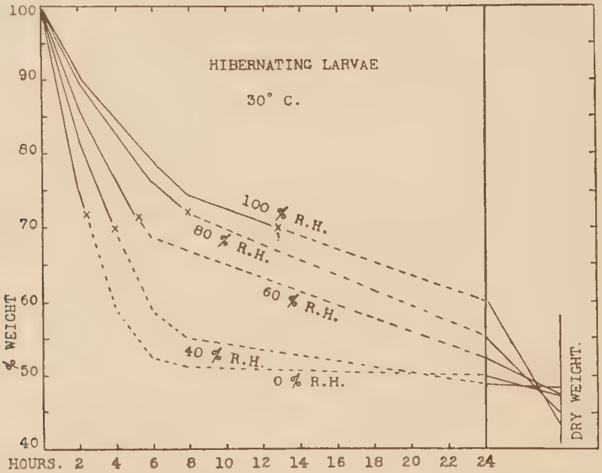

Fig. 11. Rate of loss of water in hibernating larvae of *P. papatasii* at 30°C. and different humidities.

Hibernating larvae died between 2 to 4 hours at 0 to 20 per cent. R.H., 4 to 6 hours at 40 to 60 per cent. R.H., 6 to 8 hours at 80 per cent. R.H., 6 to 24 hours at 90 to 100 per cent. R.H. These results were the same for all temperatures examined (17, 23 and 30°C.). It seems, therefore, that there is little or no difference between hibernating and active larvae in this respect.

Temperature seems to have very little effect on the loss of water either in active or in hibernating larvae. Experiments were carried out at 17, 23 and 30°C. and the curves were very similar for all three temperatures. Loss of water in the larvae seems to be proportional mainly to the relative humidity, and no constant and clear proportion could be found between the rate of loss of water and the saturation deficiency of the air. Some curves with similar saturation deficiencies at different temperatures have a very similar course, but others showed very big differences.

It is rather surprising that the larvae dry up in less than 24 hours in a saturated or nearly saturated atmosphere, *i.e.*, in a closed tube of 36 ccm. volume containing about 10 ccm. of water kept at a constant temperature. The larvae could only be kept alive for any length of time in contact with water. They were first kept on moist blotting paper (they started feeding on it but could not digest it) and then in tubes containing only a thin film of water. Larvae were kept alive in this condition for

36 days without food. During that time they lost about 30 per cent. of their original weight and their dry weight after 36 days was 19 per cent. instead of the usual 30 to 35 per cent.

Site of loss of water from the larvae.—Mellanby (1934 b) has shown that in some insects water is lost mainly by evaporation from the spiracles. But the relatively quick death by desiccation in a nearly saturated atmosphere made it unlikely that this was the case also in *Phlebotomus* larvae, and my experiments appear to confirm this view. The larva possesses only four small spiracles, one pair at the anterior edge of the second thoracic segment and one slightly larger pair at the lateral posterior corner of the eighth abdominal segment. There is no closing mechanism in the spiracle. The anterior and posterior spiracles are connected by two longitudinal tracheal tubes from which a pair of tracheae branch off in every segment, alternately dorsally in one segment (uniting in the middle line of the back) and ventrally in the next segment. The wide tracheal trunks originating from the posterior spiracles divide into several branches supplying the posterior part of the body. A similar but much narrower tracheal branch originating from the anterior spiracles supplies the head (fig. 12).

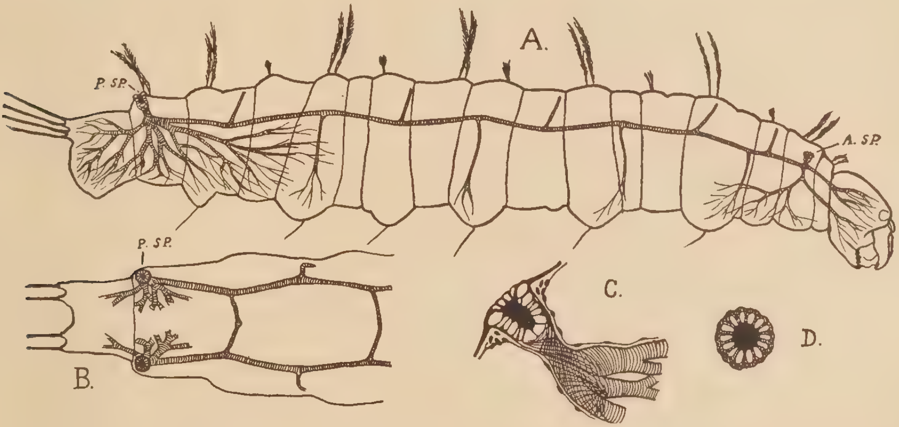

Fig. 12. Tracheal system of 4th stage larva of *P. papatasii*. Semidiagrammatic. The tracheal trunks are shown relatively too wide. A, side view ; B, dorsal view of the tracheal system of the last abdominal segments ; C, section through posterior spiracle ; D, dorsal view of posterior spiracle ; *a.sp*, anterior spiracle ; *p.sp*, posterior spiracle.

Apart from evaporation from the spiracles the possibility of excretion of water from the rectum has to be considered. Experiments were therefore planned in which some or all body openings of the larvae were closed and the rate of loss of water observed. Normal larvae were kept as a control in every experiment.

In one set of experiments a drop of paraffin wax with a low melting point (47°C.) was placed on the spiracles with a hot needle. The wax really closed the spiracles and no layer of air between skin and paraffin existed, as could be verified by submerging the larvae in water. Even a thin layer of air beneath the wax was easily visible by its different refraction. The results with these paraffined larvae were exactly the same as in the control larvae, and it is unnecessary to describe them in detail.

In a further series of experiments larvae were ligatured with human hair just behind the anterior and before the posterior spiracles. If loss of water were to take place through either the spiracles or mouth or anus, loss of water in these tied larvae ought to be less, at least during the first few hours of the experiment while the larvae are still alive. But the loss of weight was not only as great as in the control larvae, but also in nearly all experiments the loss of weight in the ligatured larvae was, even at first, more rapid than in the controls at all combinations of temperature and humidity. Fig. 13 illustrates one of these experiments. In the figures for the ligatured larvae the weight of the hair has been deducted.

It appears clear, therefore, that this larva loses water through the general surface of the body. This is not surprising, for larvae of other Psychodids are aquatic or semi-aquatic. Indeed one might almost say that the larva of *Phlebotomus* is semi-aquatic, for its existence depends on contact with liquid water and it must continually replenish its supply of water, partly by feeding on moist matter and partly by absorbing water through the cuticle. It seems that absorption through the cuticle must be important, for dead larvae kept on moist filter-paper increase in weight. We may probably assume that the larva, whether alive or dead, is continually absorbing water through its cuticle and that the weight is maintained steady in the living larva by excretion through the Malpighian tubes. This would account for the increase in weight after death, though the possibility exists that a post-mortem change occurs in the structure and permeability of the cuticle.

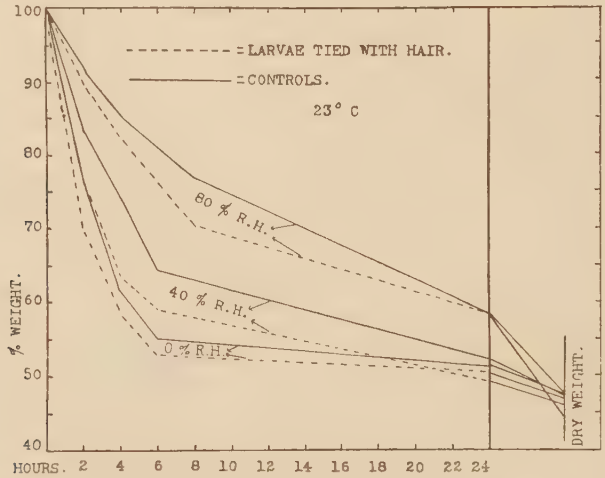

Fig. 13. Rate of loss of water from larvae of *P. papatasii* ligatured with hair and unligatured larvae as controls, at 23°C. and different humidities.

Fat content.—It has been mentioned above that the proportion of dry matter in active larvae in summer is 30 to 35 per cent., and that in hibernating larvae 44 to 48 per cent. at the beginning of hibernation and 40 to 44 per cent. in the later stages of hibernation.

The following determinations of the amount of ether soluble substances (which are mainly fat) have been carried out in order to determine whether the increase in dry weight is due to an accumulation of fat for hibernation, as in other hibernating insects. Two methods were used, first the dried, weighed and ground larvae were kept for 24 hours in ether. They were then dried again at 105°C. and weighed. The other method was a Micro Soxhlet method, and the amount of fat was weighed on a micro balance. I am indebted to Dr. Frankel, of the Department of Biochemistry of the Hebrew University, for carrying out these determinations.

A comparison of the results of the two methods showed that the simple extraction method is fully sufficient if care is taken to lose no material. The following table shows the results of the analyses.

TABLE IV.

Fat Content of Larvae of Phlebotomus papatasii.

	No. of larvae	Orig. weight of larvae in mg.	Dry weight		Fat content			Remarks
			In mg.	Percent. of orig. weight	In mg.	Percent. of orig. weight	Percent. of dry weight	
1	100	72·2	23	31·9	1·5	2·08	6·5	Active larvae
2	84	46	12·5	27·2	1·2	2·6	9·6	Active larvae in Nov. beginning hibernation
3	100	73·51	33·4	45·4	5·17	7	15·5	Hibernating larvae in December
4	100	66·94	29·8	44·5	4·43	6·6	14·9	Same
5	100	66·69	30·6	45·7	3·9	5·7	12·7	Same
6	118	71·37	29·7	41·6	4·3	6·02	14·5	Same
7	100	107	42·5	39·9	6·4	6	15	Hibernating larvae in Jan.
8	100	86	29·4	34·2	4·2	4·9	14·3	Same

The table shows that the amount of fat in hibernating larvae varies from 12·5 to 16 per cent. The results of the simple extraction experiments are a little higher, but this is due probably to loss of material at the weighing after extraction. This amount of about 15 per cent. represents rather accurately the difference in the dry weight between active and hibernating larvae. The fat content in active larvae was 5 to 6 per cent. in summer and 10 per cent. in November, when hibernation started. It is therefore justifiable to assume that the higher dry weight of the hibernating larvae is due mainly to the accumulation of fat.

The question whether the relative amount of water in the larvae diminishes during hibernation has not been investigated.

Fatal limit of desiccation.—Because of the difficulty in determining exactly the time of death only a rough calculation could be made to find out how great a loss of water was fatal for the larvae. The mean between the weight of the larvae at the last weighing at which they were alive and that at which they were found dead was taken, *e.g.*, larvae were found alive after they had lost 32 to 35 per cent. of their original weight, but these larvae were dead after they had lost 42 to 45 per cent. A loss of weight of 38 to 40 per cent. may therefore be assumed as fatal. The dry contents of active larvae are 30 to 35 per cent., *i.e.*, 65 to 70 per cent. of the body is water. The larvae die therefore if they have lost 55 to 60 per cent. *circ.* of their original water content.

Hibernating larvae were still alive after they had lost 20 to 25 per cent. of their original weight. They were dead after they had lost 30 to 35 per cent. Taking 28 to 30 per cent. as the fatal loss and a dry weight of 45 to 47 per cent., *i.e.*, 53 to 55 per cent. water content, the fatal loss is 55 per cent. *circ.* of the original water content. Both active and hibernating larvae die therefore after they have lost the same percentage of their water content, *i.e.*, 55 to 60 per cent. *circ.* The points of death in the graphs at different humidities placed according to the observed time of death are in accord with this very rough calculation.

Loss of water from pupae.—*Phlebotomus* has a free pupa which does not liberate itself completely from the cast larval skin. It generally remains adherent to the last abdominal segments and the pupa attaches itself to the ground by means of this sticky larval skin (fig. 14). The fresh pupa is creamy white, its colour changing then to yellowish ochre and shortly before hatching to blackish (due to the pigmentation of the hairs of the already fully developed adult). The eyes of the pupa are at first of the same colour as the body, then change to light brown, the middle of the facets darkening first, becoming dark brown and black. These colour changes are very constant, and the age of a pupa at a given temperature may thus be determined rather accurately. At a temperature of 30°C. the pupal stage lasts 8 to 9 days and the colour changes of the pupa at this temperature is shown in Table V.

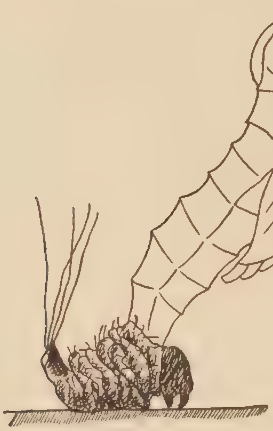

Fig. 14. Pupa of *P. papatasii* attached to the ground by the partly cast larval skin.

TABLE V.

Age	Coloration of the pupa at 30°C.	
	Body	Eyes
1st day— 0 to 12 hours	white	white
12 to 24 hours	yellow	yellow
2nd day	yellow	light brown
3rd day	yellow	brown
4th day	yellow	dark brown
5th to 6th day	yellow	black
7th or 8th day	blackish	black
8th or 9th day	hatching	

At lower temperatures the intervals for the changes described above are much longer, *e.g.*, at 17°C. the black colour of the eyes appeared after 26 days and the pupae hatched after 45 to 50 days.

Pupae were kept under the same conditions as larvae and weighed daily. It was not always possible to remove all adhering particles and particularly the larval skin without injuring the pupa. This introduced a certain error into the determination of the weights.

The pupae lost water uniformly until they were quite shrunk. No difference could be found in the rate of loss of water in the live and dead pupa. Death could only be recognised after the pupa had shrunk greatly, and the stage at which the pupae had died could afterwards be diagnosed by the coloration of the pupa as described above.

Pupa derived from active larvae.—In low humidities (0 and 40 per cent. R.H.) they lost nearly all their water in 2 to 3 days. In the high humidities (80 and 100 per cent. R.H.) the loss of water was slower, but here also the pupae lost all their water in 5 to 7 days. Temperature seems to have almost no influence, as the curves for experiments carried out at 17 and 30°C. are practically identical (fig. 15). It is rather surprising that the pupa with its relatively thick chitinous covering loses water so readily in a practically saturated atmosphere, just as the larva does. This was the case only if condensation of water was carefully prevented. If pupae were kept at the same temperatures in earthenware pots in which the relative humidity of the air was 95 per cent. *circ.*, *i.e.*, certainly not higher than in the closed tubes containing water, they lost almost no weight at all. The only difference was that in the pots the pupae were in contact with water and that condensation in little droplets always occurred. Changes in temperature and, therefore, condensation of water occur regularly under natural conditions which were much more closely imitated in the pots than in the tubes.

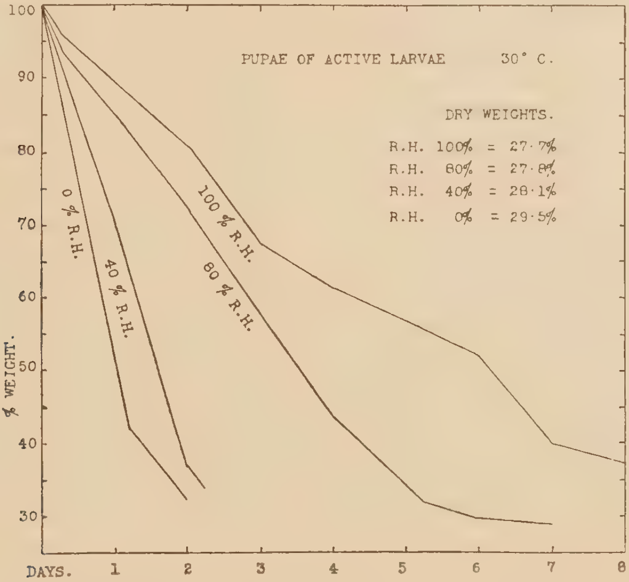

Fig. 15. Rate of loss of water of pupae of active larvae of *P. papatasii* at 30°C. and different humidities.

Apparently then the pupa needs contact water like the larva, and as the pupa normally has contact with its surroundings only by the cast larval skin attached to its tail, water probably passes through the larval skin by capillarity. The proportion of dry matter in the pupae was lower than that of the larvae (27 to 29·5 per cent.).

Pupae derived from hibernating larvae.—These pupae lost water in the high humidities much more gradually. In the low humidities (0 and 40 per cent.) curves with similar saturation deficiency at different temperatures had a very similar course, but in the higher humidities relative humidity seems to be the only factor determining loss of water (fig. 16).

Mortality in these pupae under normal conditions, *i.e.*, in pots with contact with water, was much higher than in pupae from active larvae. The dry weight was higher than in pupae from active larvae, 33 to 36 per cent. as a rule.

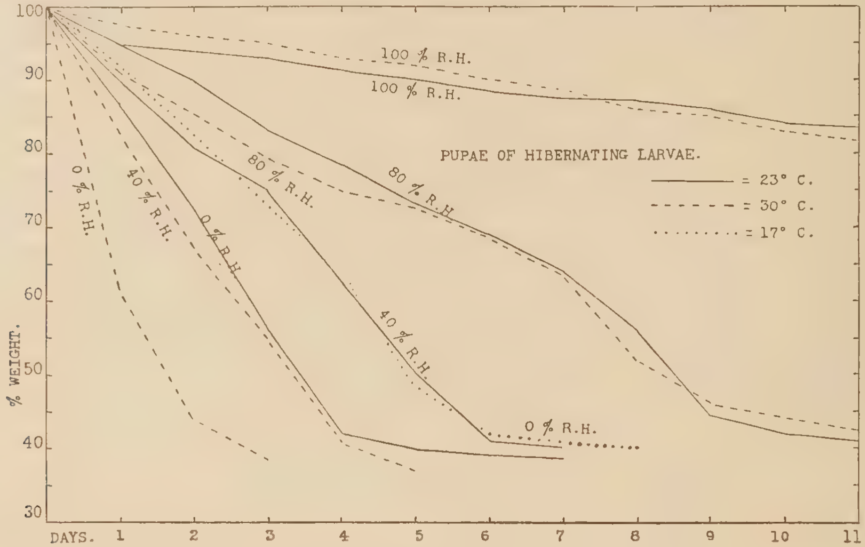

Fig. 16. Rate of loss of water of pupae of hibernating larvae of *P. papatasii* at 17°, 23° and 30°C. and different humidities.

Loss of water and its influence on development.—Pupae kept from the beginning without contact water invariably died in all experiments. Adults were obtained only from pupae which were put into the experiments at 30°C. in the middle of their development. Pupae of the same batch kept in earthenware pots hatched regularly. It appears, therefore, that development and loss of water proceed independently and that adults hatch only if the development is completed before the fatal limit of desiccation is reached. As development is much prolonged at temperatures of 17 and 23°C., while loss of water proceeds approximately at the same rate, no adults hatch at these temperatures. At 30° even in humidities of 80 and 100 per cent. loss of water is rapid enough to prohibit a complete development, although the pupal stage is only 8 days at this temperature (fig. 15). Examination of the dead pupae showed that at 30°C. in the high humidities they died in the late stages of development, sometimes shortly before hatching.

Summary.

1. The thermal limits of *Phlebotomus papatasii* are determined, 40·5° to 41°C. being the lethal temperature for females, and 42° for males after one hour's exposure. On long exposures fed females die at a lower temperature than unfed ones. Larvae die at 42° after one hour's exposure. Adult sandflies die in 2 hours at —5·5° and larvae in half an hour at —10°.

2. The length of life of *P. papatasii* at different combinations of temperature and humidity was determined. Length of life increased with the rising humidity of the air at each temperature examined.

3. Sandfly larvae and pupae have no protection against loss of water and die of desiccation in nearly saturated air if they have no contact with water.

4. Sandfly larvae lose all their water through the skin.

5. Determination of the fat content of active and hibernating larvae showed that during hibernation 15 per cent. of the dry weight of the larvae consists of fat, while in active larvae the fat content is only 5 per cent. of their dry weight.

References.

ADLER, S. & THEODOR, O. (1931-35). Investigations on Mediterranean Kala Azar I-X.—Proc. Roy. Soc. (B.), **108,** p. 447 ; **110,** p. 402 ; **116,** p. 494.

BUXTON, P. A. (1931). The thermal death point of *Rhodnius* under controlled conditions of humidity.—J. Exp. Biol., **8,** p. 275.

——. (1932). Climate in caves and similar places in Palestine.—J. Anim. Ecol., **1,** p. 152.

——. (1932). The climate in which the rat-flea lives.—Ind. J. Med. Res., **20,** p. 281.

MELLANBY, K. (1932). The influence of atmospheric humidity on the thermal death point of a number of insects.—J. Exp. Biol., **9,** p. 222.

——. (1934 a). The influence of starvation on the thermal death point of insects.—*Ibid,* **11,** p. 48.

——. (1934 b). The site of loss of water from insects.—Proc. Roy. Soc. (B.), **116,** no. 797, p. 139.

PATTON, W. S. & HINDLE, E. (1928). The North Chinese species of the genus *Phlebotomus.* Proc. Roy. Soc. (B.), **102,** p. 533

SOKOLOW, N. P. & TARWIT, I. A. (1936). La resistance des Phlebotomes au froid.—Bull. Soc. Path. Exot., **23,** p. 150.

THEODOR, O. (1934). Observations on the hibernation of *Phlebotomus papatasii.*—Bull. Ent. Res., **25,** p. 459.

A NEW SPECIES OF *NYSIUS* (HEM. LYGAEIDAE) FROM TASMANIA, AND NOTES ON THE ECONOMIC IMPORTANCE OF THE GENUS.

By J. W. Evans, M.A.,
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The genus *Nysius*, Dallas, as pointed out by China (1934), is in some respects the most cosmopolitan of all Hemipterous genera. Two species have been previously described from Australia, of which one, *Nysius vinitor*, Berg., occurs in every State of the Commonwealth. The other species, *Nysius clevelandensis*, Evans, is known only from Queensland. Below is described a third species which is apparently confined to Tasmania.

Nysius turneri, sp. n. (fig, 1).

General coloration, pale brown. Length, 4 mm. (from front of head to apex of wings).

Head marked with a pattern of black and reddish brown ; punctate and pilose. Eyes very dark brown, the inner margin rufescent. Tylus prominent, wide anteriorly, rufescent edged with black. Bucculae wide and long, almost reaching to the base of the head (fig. 1, *b*). *Pronotum* pilose, rufescent but for a transverse black bar ; posterior lateral angles black. *Scutellum* pilose, dull yellowish-brown. *Hemielytra* extending to just beyond the apex of the abdomen ; corium and clavus yellowish hyaline, pilose ; costal margin as in figure. *Legs* testaceous spotted with black. *Genitalia* ; male genital clasper as in fig. 1, *c*.

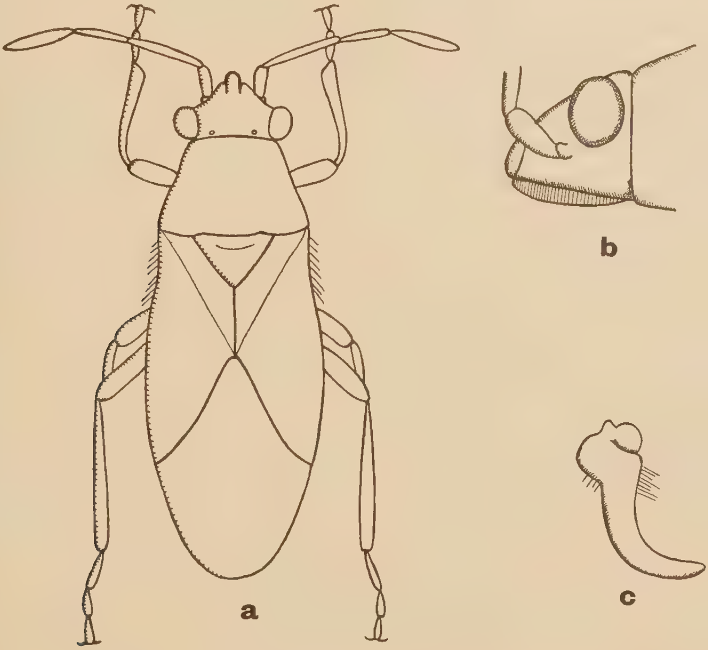

Fig. 1. *Nysius turneri*, sp. n., **a,** adult ; **b,** side view of head ; **c,** male genital clasper.

Described from numerous specimens taken on *Cotula coronopifolia*, growing on an area of reclaimed land at Invermay, Launceston.

Type in the collection of the Australian Museum, Sydney.

This species is dedicated to Mr. H. A. Turner, who for many years has been concerned with its control.

Nysius turneri may be distinguished from *N. vinitor* by the shape of the anterior costal margin of the hemielytra, and from *N. clevelandensis* by the shape of the bucculae and of the male genital claspers. Figures of these structures for both the previously described species have been given in an earlier publication (Evans, 1929).

Careful collecting in both the north and the south of Tasmania has failed to disclose the presence of *N. turneri* other than in Launceston. The area of land reclaimed from the River Tamar, on which it occurs, is situated just to the north of Invermay, a suburb of Launceston. During exceptionally dry seasons when the vegetation on the swamp dries up, the insects leave the river margin and make their way to neighbouring gardens where they cause extensive damage to ornamental plants and vegetable crops. Collections of *Nysius* spp. from Melbourne, Adelaide, Perth and Canberra, have comprised solely specimens of *Nysius vinitor*, the Rutherglen Bug. It is evident that this species, common in both open grass lands and forest country, is the most widely distributed of the Australian species. It is possible that other species occur in Australia, that are confined to specialised habitats, since isolation appears to result in rapid species differentiation within the genus.

The Economic Importance of the Genus Nysius.

Reference to the literature of applied entomology reveals the fact that only a few species of this genus are of economic significance. Yet, according to China (1934), over a hundred have been described. It is possible that a number of these are not congeric with the genotype, *N. thymi*, Wolff. For instance, as pointed out previously (1929), only two of the numerous species described from Hawaii can be correctly placed in this genus. It is also evident that several distinct species have frequently been confused and recorded under a single name. The table that follows has been compiled from papers abstracted in the *Review of Applied Entomology*. In it are listed the eleven species of the genus *Nysius* that have been recorded as injurious to cultivated crops. Doubtless representatives of every species can breed on a very wide range of plants. The few plants that have been recorded, however, suggest that preference may be shown for plants belonging to the orders Cruciferae and Compositae.

Species	Distribution	Wild food-plants	Crops attacked
senecionis, Schill	Germany, France, Italy, Spain, Algeria, Tunisia	*Diplotaxis erucoides* *Senecio vulgaris*	Vines
graminicola, Kol.	S. Palaearctic Region, including Russia		Cotton
inconspicuus, Dist.	Malaya		Tea
binotatus, Germ.	South Africa		Fruit, especially peaches; potatoes
ericae, Schill	Palaearctic and Nearctic Regions, including Bermuda, Virginia, Arizona, Kansas, Iowa, Colorado, Utah, California	*Portulaca oleracea* *Capsella bursapastoris* *Lepidium virginicum* *Artemisia tridentata* *Salsola* spp.	Fruit and vegetable crops

Species.	Distribution	Wild food-plants	Crops attacked
minutus, Uhl.	California, Arizona	*Chenopodium album*	Foliage of peach and apricot trees ; potatoes, flax
huttoni, B. W.	New Zealand		Lucerne
delectus, B. W.	Hawaii		Tobacco
vinitor, Berg.	Every Australian State		Fruit and vegetable crops, tobacco, flower heads, cotton
clevelandensis, Evans	Queensland	*Sonchus oleraceus* *Gnaphalium purpureum* *Erigeron linifolius*	Do. do.
turneri, Evans	Tasmania	*Cotula coronopifolia*	Vegetable crops and ornamental plants

Life-History and Habits.

Many short notes have been published that have given accounts of the life-history of *Nysius* spp. In addition two complete biological studies have been made. These are concerned with *Nysius ericae* (Milliken, 1918) and an Australian species, probably *Nysius clevelandensis* (Smith, 1927). The life-history presents no unusual features. Eggs are deposited in loose soil, rubbish and in flowers, and the nymphs in the first three instars seldom wander far from their food-plants.

With all species, outbreaks appear to be associated with abnormally dry summers. The drying up of the native vegetation which usually supports the insects force them to feed on such green leaves or fruit as may be available in their immediate neighbourhood. Since in Australia dry summers are not always accompanied by outbreaks of *Nysius*, other factors must be concerned in these fluctuations in abundance. These may be in part of a biological nature. Whilst no parasites have been noted in Australia, *Nysius ericae* in America is parasitised by a Tachinid, *Phasia occidentis*, Walk. (Milliken & Wadley, 1923). It is, however, probable that the effect of climate is of more importance in this respect. The incidence of past epidemics suggests that abnormally wet winters preceding hot dry summers are of significance.

Control.

Nysius, in common with other insects that appear suddenly in large numbers only in occasional seasons, are difficult to control. Breeding sites of limited extent that are adjacent to areas carrying valuable crops may be treated, where practicable, by burning or cultural methods. Smudge fires are of value for driving the insects off fruit crops, and for field crops hopper-dozers have been employed with success. Chemical control methods are seldom practical because of their expense, though successful control has followed the application of dusts containing either pyrethrum or calcium cyanide.

References.

China, W. E. (1934). A new species of *Nysius* from West Africa.—Entomologist, **67**, p. 235.

Evans, J. W. (1929). A new species of *Nysius* from Australia.—Bull. Ent. Res., **19,** p. 351.

Milliken, F. B. (1918). *Nysius ericae,* the False Chinch Bug.—J. Agric. Res., **13,** p. 571.

Smith, J. H. (1927). Life-history Notes on the Rutherglen Bug.—Queensland Agric, J., **27,** p. 285.

Milliken, F. B. & Wadley, F. M. (1923). *Phasia* (*Phorantha*) *occidentis,* Walker, an internal parasite of the False Chinch Bug.—Bull. Brooklyn Ent. Soc., **18,** p. 28.

THE PROBLEM OF BLACK SCALE (*CHRYSOMPHALUS FICUS*, ASHM.) IN PALESTINE.

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Palestine Entomological Service.

(Plate XIX.)

Foreword.

The work which is described in this paper was undertaken owing to the conflicting results of standard fumigation practice in Palestine as it existed up to 1932, so that it became evident that the response of the Black Scale to Palestine conditions called for investigation.

Owing to the difference in climate between the Northern Coastal Plain and the Jordan Valley a series of parallel investigations had to be initiated, with the interesting results which Dr. Schweig and Mr. Grunberg have set forth.

There seems little doubt that the growers in the Jordan Valley will have to change from summer to winter fumigation and that in Acre Sub-District even if the double fumigation now under trial is not practicable (and there is no reason why it should not be) fumigation will have to be completed by the end of July—otherwise the fruit of the last fumigated groves will be infested before the gangs can reach them. With regard to biological control, this would be of more value for keeping down the Black Scale population on alternative hosts, such as Eucalyptus groves and roadside trees. Negotiations for the importation of *Comperiella bifasciata* are in progress, and if this proves possible it will be given a trial in the Jordan Valley and the Coastal Plain.

It is unfortunate that the pressure of other demands on the time of a small staff precluded the investigation of the behaviour of the Black Scale in Jaffa Sub-District, but general observations show that it tends to react more in the manner of the Jordan Valley race than of that of the Northern Coastal Plain.

All the orange-groves between Jaffa and Haifa are heavily infested with *Aonidiella aurantii*, and it will be interesting to see, in view of the observations on mutual tolerance contained in this paper, whether Black Scale spreading from Jaffa will drive out the Red Scale or fail to make headway against it.

E. Ballard.

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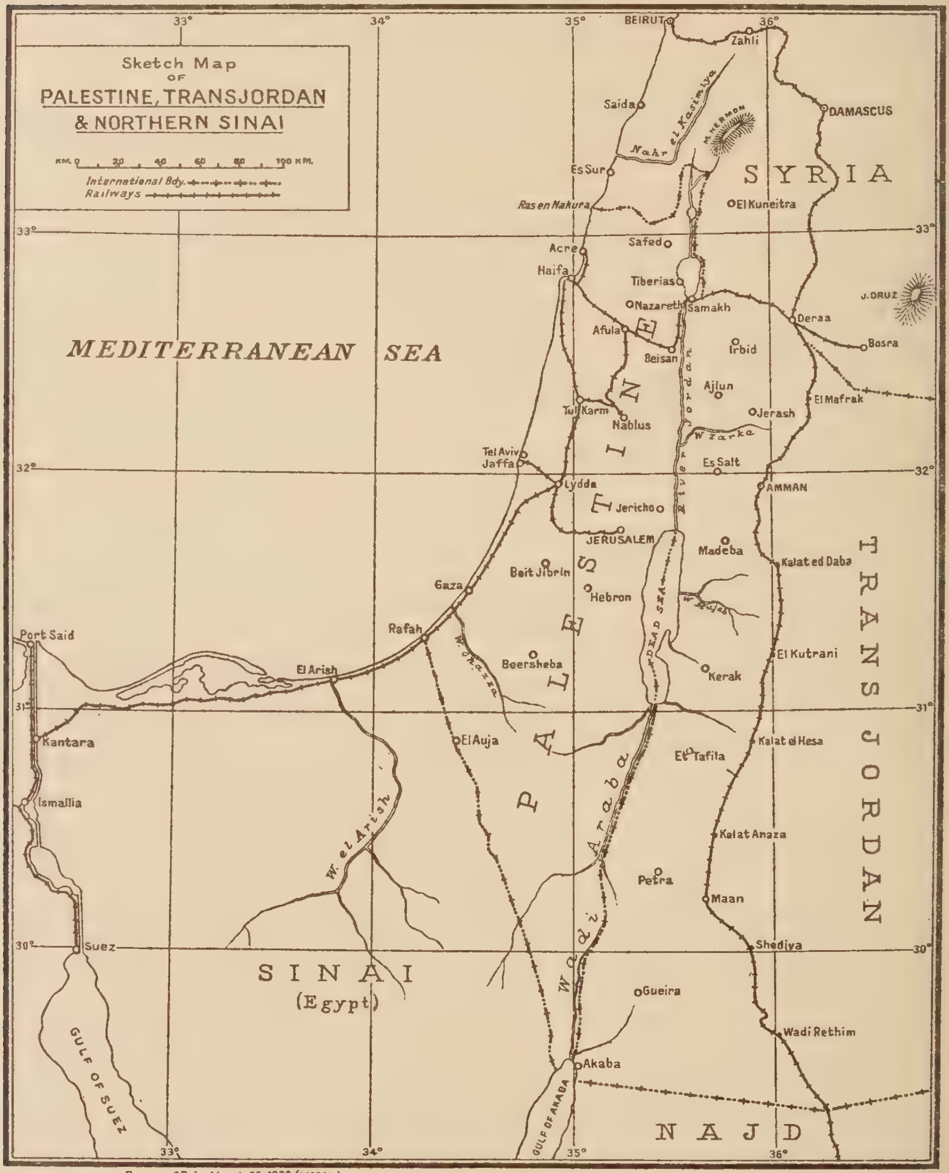
1. Climate of Palestine.

Coastal Region of North Palestine.

The Acre area extends from the Haifa-Acre Bay northwards along the coast of Palestine to the Ras-en-Naqura on the Syrian frontier.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GULF OF AKABA

Survey of Palestine Jaffa 1932. (0/29/32)

Fig. 1. Sketch-map of Palestine.

It is a broad plain bordered on the east, north-east and south-east by the slopes of the Galilee and Carmel mountains, and is characterised by the prevalence of sand-dunes in the southern part and of medium and heavy soils in the northern part with abundant natural water and a relatively high water-table. This gives the farmer ample opportunity for the cultivation of vegetables, Citrus and other fruit.

The climatic conditions are those of a coastal plain. The sea exercises its tempering influence throughout the year, so that the temperature on days when the " Khamseen " wind blows does not exceed 42–43°C. The yearly average temperature for 1934 was 19·3, and the monthly averages in 1934 were :—

TABLE I.

Month	Abs. minim. temp.	Abs. maxim. temp.	Mean of day	Relative humidity 8 a.m.
	Degrees C.	Degrees C.	Degrees C.	Per cent.
January	1·6	27·0	12·3	59
February	1·4	22·0	10·5	70
March	4·5	30·8	15·7	48
April	7·2	30·0	17·4	65
May	10·5	33·4	20·5	61
June	18·7	29·0	24·3	62
July	16·9	30·0	24·5	62
August	17·3	32·5	26·5	64
September	15·0	32·0	25·0	59
October	13·3	13·0	22·6	59
November	10·5	30·0	20·0	51
December	5·5	25·3	14·0	72

The relative humidity is very high, and the dew during the summer months is often very heavy ; only on " Khamseen "* days does the air humidity drop considerably, to 20 per cent. and lower.

The actual rainy season is to be counted as from November up to the beginning of April, the rainfall varying considerably. In years with a small rainfall the total is about 450 mm. ; normally it reaches 500–550 mm. In the year 1934–35 the rain was exceedingly heavy, totalling 763 mm. ; in 1933–34 it was 466 mm.

January and February are the months with the lowest average temperatures and highest rainfall. During these months strong sea winds (W., S.W.) and gales are frequent, even causing, though restrictedly and rarely, heavy falls of fruit in the Citrus groves. In the forenoon and up to 2 p.m. winds from the sea prevail (W., S.E.), changing direction towards the sea later in the afternoon (E., N.E., S.E.). The average velocity of winds during the summer ranges from 15 to 20 miles an hour.

" Khamseen " winds bring waves of hot air from the desert towards the east at the beginning and end of the summer and are noted for their high maxima (42–43°C.) and very low relative air humidity. In the coastal region their temperature extremes are somewhat moderated by the presence of the sea, when compared with the conditions in the Jordan Valley.

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* " Khamseen " or " Sharqia " are hot easterly winds usually causing a sudden rise of temperature.

Jordan Valley.

The Jordan Valley is a link in the Syria-African system of valleys beginning in the north of Syria and going through the Dead Sea and the Red Sea down to Lake Nyasa.

Though the Jordan Valley is of considerable length, only a single sector of it will be discussed here, *viz.*, the Lake of Galilee and its immediate vicinity.

This lake is about 200 metres below sea-level, 21 km. long and 11 km. broad. A small but very fertile valley is formed on the N.W. of the lake, known as the Genosar valley (Naphtali). Another in the south, where the Jordan leaves the lake, is El Ghor. Except for these two cases the lake is surrounded by a chain of very steep hills. It is in the valleys that Citrus is cultivated.

The most important factor influencing the climate of the Jordan Valley is its depression—responsible for the unusual heat there. The average temperature for the year 1934 was 22·8°C., the normal average at Tiberias being 22·5°C. The monthly temperatures during the year 1934 were as follows :—

TABLE II.

	Average	Minim.	Maxim.
	Degrees C.	Degrees C.	Degrees C.
January	13·3	2	25
February	11·7	7	23
March	18·5	6	35
April	21·8	10	38
May	26·5	14	44
June	29·7	16	45
July	30·95	20	43·5
August	30·83	22	42
September	28·4	19	42
October	25·3	17	30
November	22·2	9	36
December...	15·3	8	22

The low relative humidity during the summer increases the effect of the temperature. During the hot season the relative humidity is almost constantly somewhat below 50 per cent. after 8 a.m. till the evening. During the night it is generally between 50 and 60 per cent. No dew can be observed all the summer and on days of the " Kkamseen " the relative humidity drops to 15–20 per cent. and even less. The influence of the lake in raising the humidity is to be observed only within a small radius.

The last few years having been years of poor rainfall in general, the amount of rain in the Jordan Valley was about 300–350 mm. During the winter of 1934–35, however, the total rainfall at Migdal was 620 mm. ; an average of 450 mm. is cited as normal (this could not be verified for Tiberias).

As to the winds, precise observations were taken during a space of nearly 2 years—and it may be stated that their direction, velocity, duration and periodicity, are very regular, especially in the hot season of the year. In the morning (07·00 hours) a slight S.E. breeze from the lake of a velocity about 2–4 miles an hour begins to blow as early in the year as March–April and continues all the summer until October. This breeze is of a local character only and has a short radius of influence ; it ceases at about noon, when the western wind makes its appearance.

The western winds are of the greatest importance in the Jordan Valley. They come from the Mediterranean, but in crossing the bare hills of the country they lose their humidity and coolness, and as a result of falling 200 metres below sea-level they increase in temperature. These western winds are rather hot during 12·00–17·00 hours and become cool only later in the evenings. Their velocity is considerable, 20–30 miles an hour in the afternoons being recorded. In the evenings the velocity gradually decreases, and after midnight the wind ceases entirely. These winds begin in April and continue all the summer till October. In October–November they cease and there are as many as 10–15 windless days a month.

The third category of winds are the so-called " Khamseen " winds ; their velocity is in general very restricted, but they are characterised by high temperatures and very low humidity. The temperature maxima caused by " Khamseen " winds in the Jordan Valley are as high as 40, 42, 44 and even 46°C., whereas the normal temperature maxima very rarely surpass 35–37°C. The influence of these winds upon the fauna and flora is disastrous.

2. Host-plants of Black Scale.

The Black Scale is an insect of polyphagous habits, with a marked preference for the genus Citrus and usually not encountered outside the Citrus region in Palestine ;* but the list of its host-plants is a lengthy one.

The adaptation of Black Scale to its hosts varies greatly according to the plants themselves, the climatic and geographical conditions of different countries and even of different areas of the same country. Thus a given plant may become heavily infested with Black scale in the Jordan Valley district, and display slight, moderate or no infestation in the other belts of its distribution. In Palestine Acre may be taken as an example where carob, myrtle, etc., do not show much infestation of Black Scale, whilst at Migdal (Tiberias) they are copiously attacked. The same can be said of Eucalyptus trees, which are sometimes heavily infested in Galilee (Capernaum), though relatively free at Acre.

All kinds of Citrus trees suffer badly from Black Scale ; but the following order of preference may be taken as characteristic of the Jordan Valley : Grapefruit, orange, mandarine, and lemon. In the Acre region the relative degree of infestation may be indicated as follows : orange, lemon and mandarine (no grapefruit is cultivated here).

Another fact to be mentioned is that for the full installation of Black Scale in new areas two to three years of undisturbed activity are needed. During the first year the infestation rises from slight to moderate (as observed in the case of successful winter fumigation), during the second year from moderate to copious, and finally from copious to heavy.

As to susceptibility and adaptation of Black Scale to its host-plants, two groups can be distinguished : (1) True host-plants, giving the insect the possibility of establishing a continuous yearly life-cycle and thus becoming a source of permanent infestation and in some cases a danger to other host-plants ; and (2) occasional host-plants, with a limited number of generations through the year (1–2), depending on the time of infestation and the physiological conditions of the plant. For instance, on the vine, of which the normal leaf-fall begins in October, there would probably be only two generations of Black Scale according to the earlier or later infestation of the plants.

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* Only in a single case was Black Scale observed in a Eucalyptus grove at a place about 6 kilos. distant from the nearest Citrus grove (Yavniel, Tiberias Sub-District) infested with the Black Scale.

Primary Host-plants.

Citrus sp.	Rutaceae
Musa sp.	Musaceae
Eucalyptus sp.	Myrtaceae

Secondary Host-plants.

Ficus elastica	Moraceae
Anona sp.	Anonaceae
Spartium sp.	Leguminosae
Acacia cynanophyla	Leguminosae
Myrtus communis	Myrtaceae
Zizyphus sp.	Ramnaceae
Phoenix	Palmae
Washingtonia	Palmae
Hedera helix	Araliaceae

Occasional Host-plants.

Vitis vinifera	Vitaceae
Nerium oleander	Apocynaceae
Punica granatum	Punicaceae
Ficus sp.	Moraceae
Cupressus (fruits)	Coniferae
Ricinus	Euphorbiaceae
Convolvulus sp.	Convolvulaceae
Duranta	Verbenaceae
Brachychiton	Sterculiaceae
Cynodon dactylon	Graminae
Sorghum halepense	Graminae

Plants known as hosts of importance in other countries, such as, olive and loquat (*Eryobotrya japonica*) in Egypt, and *Hibiscus* and *Pittosporum* in North Africa, are not included in the list of hosts in Palestine. They were never observed to be infested with Black Scale in Acre or Migdal, although in the vicinity of trees with a heavy population of the Scale.

The observation of Balachovsky that plants of foreign origin are more subject to Black Scale attack than endemic plants seems to be correct for Palestine, as shown by the foregoing list. As to the plants which are occasional hosts of the scale it may be said that their economic importance is very limited. However, among them certain weeds, such as Bermuda grass (*Cynodon dactylon*), broom corn (*Sorghum halepense*), *Convolvulus* and others occurring in the Citrus groves, can become a source of reinfestation after fumigation, if they are not destroyed before treatment. This applies to the Jordan Valley only, as in Citrus groves of the Acre area no Black Scale was observed on weeds.*

3. Distribution of Scale on the Plant.

Black Scale fixes itself on Citrus fruit of all ages and on the leaves and young green twigs ; never was infestation observed on woody branches or stems covered with bark. No preferences were noted as between leaves and fruit, or between lower and higher situations on the trees ; badly infested leaves and fruits were observed up to a height of about 5–6 metres from the soil, this being the upper limit of spread.

The number of scales on a single leaf can be very high, especially toward the end of the hot season (October and November). Leaves were observed at Migdal bearing about 300 scales, whereas in Acre the maximum did not exceed 150 scales to a leaf. The minimum number of scales on leaves is to be found during March, April and May (Acre) after the rains, before the start of the summer expansion and under the influence of the hot " Khamseen " winds. The upper surface of leaves is generally less infested than the lower, especially on the sunny side of the tree (*i.e.*, S.E.). Often an equal distribution of the scale on both sides occurs in shady parts of the tree, for the insects seem in general to prefer places not subject to direct sunlight. Males show a definite preference for the upper side of the leaf, where they form large continuous colonies (*cf.* Priesner).

The problem of the distribution of Black Scale on the tree in relation to its exposure was studied in both Acre and Migdal during two years by picking at fixed dates of every month a given quantity of leaves from each cardinal point of the compass. The results of these examinations may be expressed as follows :—

The Black Scale shows preference for settling in shade during the months of greater heat and on the sunny side of trees during the cooler period of the year. As the climatic conditions of the Acre and Jordan Valley areas differ, and also the number of generations of the insects in those areas, a small divergence in behaviour of the scales results. In Acre Sub-District, the last generation arising in October (autumn–winter generation) fixes itself on the sunny side of the tree and gives birth after winter to a spring generation (April) which remains still in the sun ; the offspring of the first summer generation goes to the shady side of the tree and remains there for another brood up to the beginning of autumn.

In the Jordan Valley the situation is as follows : From May till September–October the majority of the Black Scale is distributed on the S.E. of the tree, then a change in the distribution occurs and the N.W. becomes more affected. This change in the distribution is due to the migration of the crawlers in August from S.E. to N.W. of the tree, becoming visible only in September–October. Finally the cessation of the strong westerly winds in the late summer in the Jordan Valley enables the crawlers to settle in the western part of the tree. As there is practically no new expansion during December–March, the situation remains unchanged throughout the winter ; only in April–May is there a new re-distribution of the scale from N.W. to S.E.

Whether these changes of distribution are due to an active migration of the crawlers or are results of an increase of mortality of larvae exposed to the influence of the direct rays of the sun is not yet clear. The following tables show the distribution of adult females on the trees during the period of observation (1933–35) at Migdal and Acre.

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* In Acre Sub-District only on *Vitis* and *Nerium oleander* slight infestation of Black Scale was exceptionally seen.

The generation arising in August (second summer generation) sends its settlers to E. and S. for the colder portion of the year (October–April). The spring generation (second decade of April) settle W. and N. for the warmer period of the year June–August. Large numbers of adult females settled in E. and S. during March, April and May are obtained because the mothers of the spring brood are fixed in their respective places from October.

TABLE III.

Showing Distribution of Adult Females on Trees throughout the Year ; Acre, October 1933–*April* 1935.

Month	East	West	South	North
1933	Per cent.	Per cent.	Per cent.	Per cent.
October	33·86	21·40	30·75	16·91
November	33·16	20·84	29·85	16·08
December	28·68	17·17	29·43	24·14
1934				
January		No evaluation was made.		
February	32·79	15·50	33·44	18·18
March	30·49	24·94	31·38	13·04
April	33·60	18·44	34·45	12·29
May	31·48	15·81	36·45	14·67
June	11·39	35·39	14·92	38·30
July	12·47	27·10	17·06	43·10
August	13·38	36·54	14·50	49·49
September	16·47	40·11	11·83	31·60
October	30·57	18·74	34·84	15·84
November	29·12	23·25	32·44	15·19
December	33·82	24·18	28·96	13·02
1935				
January	33·92	24·62	26·42	15·03
February	—	—	—	—
March	30·0	18·31	38·10	13·52
April	30·50	18·24	28·93	22·19

TABLE IV.

Black Scale Distribution, Migdal.

Date of examination of leaves	Total no. of scales on 20 leaves	North		West		South		East	
		No. of scales on 5 leaves	Per cent. of total number	No. of scales 5 leaves	Percent. of total number	No. of scales on 5 leaves	Percent. of total number	No. of scales on 5 leaves	Per cent. of total number
25.vii.33	3,454	354	10·2	554	16·1	1,214	35·1	1,332	38·6
25.viii.33	3,398	366	10·7	544	16·0	1,311	38·5	1,177	3·46
25.ix.33	2,888	636	22·0	505	17·5	1,112	28·6	635	22·0
25.x.33	2,282	359	15·7	596	26·1	679	29·7	648	28·4
27.xi.33	4,525	1,098	24·3	1,497	32·9	1,215	26·8	425	16·6
27.xii.33	2,461	857	34·4	517	21·0	530	21·5	557	22·6
26.i.34	1,853	660	35·6	413	22·3	330	17·8	450	24·3
25.ii.34	1,759	735	41·7	574	32·6	129	7·2	321	18·2
26.iii.34	509	62	12·1	245	48·0	96	19·0	106	20·8
25.iv.34	542	70	13·2	156	29·4	136	25·6	170	32·0
27.v.34	474	108	23·0	85	18·0	107	22·0	174	37·0
26.vi.34	929	234	25·1	159	17·0	283	30·4	253	27·2
25.vii.34	1,190	340	28·5	130	10·9	230	19·3	490	41·1
27.viii.34 ...	1,742	453	26·0	239	13·7	545	31·3	505	28·1
28.ix.34	3,110	1,100	35·5	765	24·6	780	25·1	465	15·0
27.x.34	4,040	1,055	27·1	1,210	29·9	1,105	27·3	630	15·5
27.xi.34	3,415	1,165	34·1	915	26·8	720	21·1	615	18·0
27.xii.34	2,950	1,010	34·0	725	24·4	630	21·2	585	19·7
27.i.35	4,060	1,690	42·0	1,005	25·0	505	12·0	860	21·0

4. Predisposition or Immunity of Citrus to Attack.

No tendency to immunity or predisposition was observed on different Citrus trees in relation to Black Scale, and all trees of the genus grown in Palestine are equally subject to infestation. Experiments carried out on seedlings at Migdal suffering from lack of water proved that the development of Black Scale on them stopped after some time. This was further confirmed by the high mortality noticed in the unwatered or abandoned groves in Acre and Jaffa.

It was observed that neglected groves are no more liable to Black Scale attack than others and that the scale developed vigorously in groves with healthy trees, where proper care and cultivation was the rule, moreover groves that were over-watered and over-manured had a higher population of Black Scale than groves that were neglected. It seems that, all other conditions being the same, this practice is the sole cause for increase in the attack of the scale.

Finally, the idea of growing Citrus varieties resistant to Black Scale must be abandoned as no such varieties were observed.

5. Factors affecting the Spread of the Scale.

Seedlings.

Seedlings must be regarded as the chief factor in propagation of Black Scale and especially in its penetration into new areas ; even when inspection of seedlings before transport is careful the possibility of infestation is not excluded.

Fruits.

In view of the importance attributed to picked fruits and peels in the spread of Black Scale, a minute study of the question during the fruiting season of 1933–34 was made. The following is the description of work at Acre laboratory. Five tests were carried out, three in the field and two in the laboratory, with 200 oranges and the same number of lemons in order to get the influence of drying-up of the fruits upon the vitality of the scale. Examinations were made every ten days and two fruits freshly picked served as a control.

TABLE V.

Number of Days that Scales survived after Picking.

Test No.	Fruits	Peels
1	70	8
2	48	12
3	50	6
4	60	17
5	50	—

TABLE VI.

Field Test of Survival of Black Scale on Fruits and Peels at Acre.

		21.ii.	27.ii.	4.iii.	9.iii.	19.iii.	30.iii.	10.iv.
ORANGE :—								
Female	Dead ...		29	—	35	55	114	
,,	Living ...	Beginning of test	126	—	64	56	61	All dead
Percent.	Living ...		80·13	—	64·64	50·45	34·85	
Male	Dead ...		27	—	64	17		—
,,	Living ...		9	—	35	2	All dead	—
Percent.	Living ...		25·00	—	35·35	10·52		—
CONTROL :—								
Female	Dead ...	17	68	—	118	95	—	—
,,	Living ...	210	167	—	303	190	—	—
Percent.	Living ...	92·51	71·06	—	71·97	66·66	—	—
Male	Dead ...	40	38	—	70	33	—	—
,,	Living ...	10	26	—	39	24	—	—
Percent.	Living ...	20·00	40·62	—	35·80	42·10	—	—
PEEL :—								
Female	Dead ...		39	31	17		—	—
,,	Living ...	Beginning of test	82	5	2	All dead	—	—
Percent.	Living ...		67·76	13·88	10·52		—	—
Male	Dead ...		26		—	—	—	—
,,	Living ...		3	All dead	—	—	—	—
Percent.	Living ...		10·34		—	—	—	—
LEMON :—								
Female	Dead ...		23	—	66	21	34	
,,	Living ...	Beginning of test	48	—	68	47	24	All dead
Percent.	Living ...		67·60	—	50·74	69·11	41·34	
Male	Dead ...		24	—	39		—	—
,,	Living ...		7	—	10	All dead	—	—
Percent.	Living ...		22·58	—	20·40		—	—
CONTROL :—								
Female	Dead ...	57	—	—	45	40	23	—
,,	Living ...	148	—	—	165	152	177	—
Percent.	Living ...	72·20	—	—	78·57	79·16	88·50	—
Male	Dead ...	108	—	—	119	96	63	—
,,	Living ...	80	—	—	26	18	13	—
Percent.	Living ...	42·55	—	—	17·93	15·78	17·10	—
PEEL :—								
Female	Dead ...		22	21	14		—	—
,,	Living ...	Beginning of test	29	3	2	All dead	—	—
Percent.	Living ...		56·85	12·50	12·50		—	—
Male	Dead ...		60	40	—	—	—	—
,,	Living ...		7	1	—	—	—	—
Percent.	Living ...		10·44	2·43	—	—	—	—

As becomes evident from this table, adult females of Black Scale survived under field conditions 50–70 days (February, April) as compared with the normal longevity of the same generation on picked fruits. At Migdal during the summer the death of full-grown females on picked fruits occurred 3–4 weeks after picking.

As to the process of oviposition on picked fruits it was observed that it started 30–35 days after picking. The larvae settled on these fruits and died after the first month owing to the fruits' decay. It seems that the premature ripening of the peel of the picked fruits conveys to the scale a stimulus to increased oviposition and creates favourable conditions for the larvae, which tend to settle almost immediately. On peels the adult females survived from 6 to 17 days.

Out of these tests the question arose whether fruits heaped underneath clean trees or peels scattered in a clean grove would become a source of infestation. Subsequently badly infested fruits were put under clean trees (Acre and Migdal) with branches at different distances from the soil and left for a long time (1–2 months). In no case was it observed that an infestation of the trees took place, with the exception of some trees with branches sweeping the soil and coming in immediate contact with the infested fruits. In our opinion, therefore, the fruits are little (if at all) responsible for the spread of Black Scale from one area to another.

Leaves.

As to leaves, their rôle in infestation of groves is more important, as the dropped infested leaves are easily transported by the wind from one place to another. In nurseries or in old groves with trees close to one another and having branches touching the soil, dropped infested leaves are a dangerous means of spread, as the death of the full-grown and ovipositing females occurs on them slowly after a week or more (especially on irrigated soil and under shade). Under laboratory conditions living crawlers were observed three weeks after the leaves had been plucked.

Contrary to the case of dropped fruit, dropped and drying up leaves do not offer conditions suitable for the crawlers, which are forced to migrate.

Manure.

A series of tests carried out from July 1933 to February 1934, negatives the possibility of manure becoming a source of distribution of the pest. Tests were made in a Citrus grove at Acre (Government Stock Farm) on two heaps of manure, cow and sheep. The infestation was done with leaves, fruits and peels arranged on the surface and at depths of 20 and 40 cm. In each test daily measurements of temperature at noon were taken. No test exceeded 10–15 days. The manure on the surface became hotter than the lower layers, sheep manure having a higher temperature than cow manure. In July 1933, the temperatures on the surface, at 20 cm. and at 40 cm. depths, respectively, were, for cow manure : 35, 31, 31°C., for sheep manure : 40, 34, 36°C. Leaves were scorched in the first days of every trial and the crawlers perished or vanished. At the beginning of winter after slight rains the temperature in the heaps rose to 40–52°C. owing to fermentation, and the oranges used were cracked on the second day of the test. In winter the temperature in the heaps was low (15–18°C.) and the excess of humidity in them caused the oranges to rot. The manure itself does not give any opportunity to the crawlers to settle, chiefly owing to the lack of chlorophyll. The crawlers die or, if they escape the heat, are compelled to migrate and must find a coincidence of the most favourable chances in order to arrive at a place fit for settling.

Manner of Spread.

The manner in which Black Scale spreads in a given grove was observed during the summer of 1934 at Migdal. Unfortunately, observations had to be limited to a relatively small number of trees. The results, however, were very interesting, and the whole proceeding was as follows :—

In a fumigated grove with a satisfactory kill one tree was left unfumigated, this tree being moderately infested at the beginning of the observations in the spring of 1934. The fruits from the encircling trees were subsequently picked on 19th December 1934 from each tree separately, their number counted and the percentage of infestation evaluated. The following diagram (fig. 2) represents the site of the trees under observation in relation to the unfumigated tree which is considered as a centre of infestation.

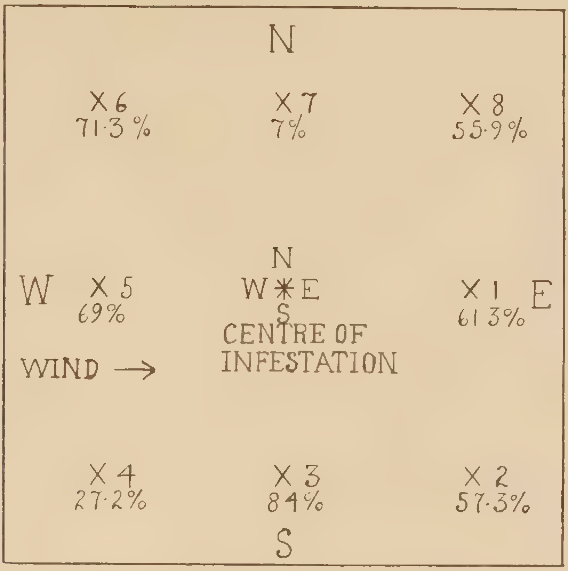

Fig. 2. Reinfestation by an unfumigated tree.

The results of counting were as follows :—

Number of tree	Number of fruits			Percent. of infestation	Remarks
	Clean	Infested	Total		
1	36	57	93	61·3	
2	67	90	157	57·3	
3	22	116	138	87·0	
4	136	51	187	27·2	
5	61	107	168	69·0	
6	101	71	172	71·3	
7	67	5	72	7·0	This tree is still young, as seen from the number of fruits
8	67	85	152	55·9	

NOTE.—The term clean fruits covers fruits absolutely free from Black Scale or with a number of scales not exceeding 5 per fruit. The trees in this grove are spaced 6 m. × 6 m.

An examination of the figures obtained proved that trees situated at the eastern zone of the infested tree, *i.e.*, trees exposed during all summer to the influence of the western wind (velocity about 20–30 miles an hour during 8–10 hours a day)* are, if at all, only in a feeble degree more infested than others. Actually all trees were infested in nearly the same degree except trees 4 and 7 (7 is still young, as can be seen from the quantity of fruits collected).

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* Wind measured by a Negretti & Zambra anemo-biograph in the same grove, and the records of the winds during the year 1934 are at the Department of Agriculture and Forests, Jerusalem.

Admitting that the kill after fumigation was equal on all the trees under observation, it can be said that in spite of the permanent activity of a westerly wind of considerable velocity and duration, reinfestation took place in concentric circles and not, as might be expected, excentrically.

6. Damage caused by Black Scale.

The damage caused to trees by Black Scale expresses itself in many ways, such as defoliation resulting from absorption and decomposition of chlorophyll, drying up of young twigs, decrease of the crop caused by poor blossom, premature dropping of attacked fruits, and fruits undersized and lacking juice.

The most prominent of all damage done is defoliation, which was observed twice during the year at both Acre and Migdal (March and October). This defoliation can be considered as a kind of self-defence of the tree. In some cases, however, the leaf-fall becomes so great as to cause the drying up of the tree. The defoliation for March (Migdal) and for October (Acre) is sometimes so severe that it is impossible to find leaves with a large number of scales upon them. At Migdal the leaf-fall coincides unfortunately with the start of the development of the new scale generation after winter, and soon the new vegetation becomes reinfested by Black Scale migrating from the remaining leaves and from other plants (showing the advantage of polyphagy for the species).

The October defoliation at Acre is accompanied by an extremely heavy drop of fruit, so that trees are standing entirely bare at the beginning of November. Blossom is very scarce on the defoliated trees, the formation of new leaves absorbing all the creative forces of the tree.

7. Relation between Black Scale and Red Scale.

Although these two species display in general many common habits and a marked morphological and biological analogy (the same duration of the developmental cycle, the same number of generations, etc.) and only small differences in their respective ecological exigences (non-coincidence of maximum activity), yet they do not occupy the same territorial zones, or if they do, it is observed that one species is always reduced to an inferior or latent status.

It is of interest to note that Black Scale and Red Scale zones may be situated at a distance of only several kilometres from one another, and in every one of these zones a specific Coccid population remains predominant. Thus, for instance, on the southern part of the Lake of Galilee (Daganya A. and B., Kinnereth, Betanya) there is a vigorous Red Scale development and only isolated cases of Black Scale ; on the contrary, the groves of the northern shores of the lake, about 20–25 kilos. distant, are badly attacked by Black Scale (Capernaum, Tabgha, Migdal) and not or rarely by Red Scale, although it was proved that Red Scale is able to develop there. Factors that are favourable to one of these species and not to the other are not yet known. It is not clear whether these factors are of an ecological character, or whether there are influences in the soil ingredients or any others. Sometimes the predominance of one species over the other can be explained by the non-coincidence of their maximum activity (or ecological factors), as will be seen from the following example at Migdal, but this explanation is not always applicable, and further investigations are necessary before conclusions can be drawn.

The following fact was observed in the insectary at Migdal : A number of Citrus seedlings were artificially infested with Red Scale in April 1934, and put between seedlings badly infested with Black Scale. During the first 2–3 months the development and reproduction of Red Scale was good and a multitude of Red Scale soon covered leaves and stems of the infested seedlings. Though the developmental cycle of Red Scale is somewhat shorter than that of Black Scale (there was always a difference of about 4–5 days per cycle), the Red Scale is less prolific and the mortality of its crawlers and young larvae was higher than that of Black Scale during the hottest months at Migdal, thus resulting in a more restricted incidence of Red Scale as compared with Black Scale. As a consequence of the double attack of Red Scale

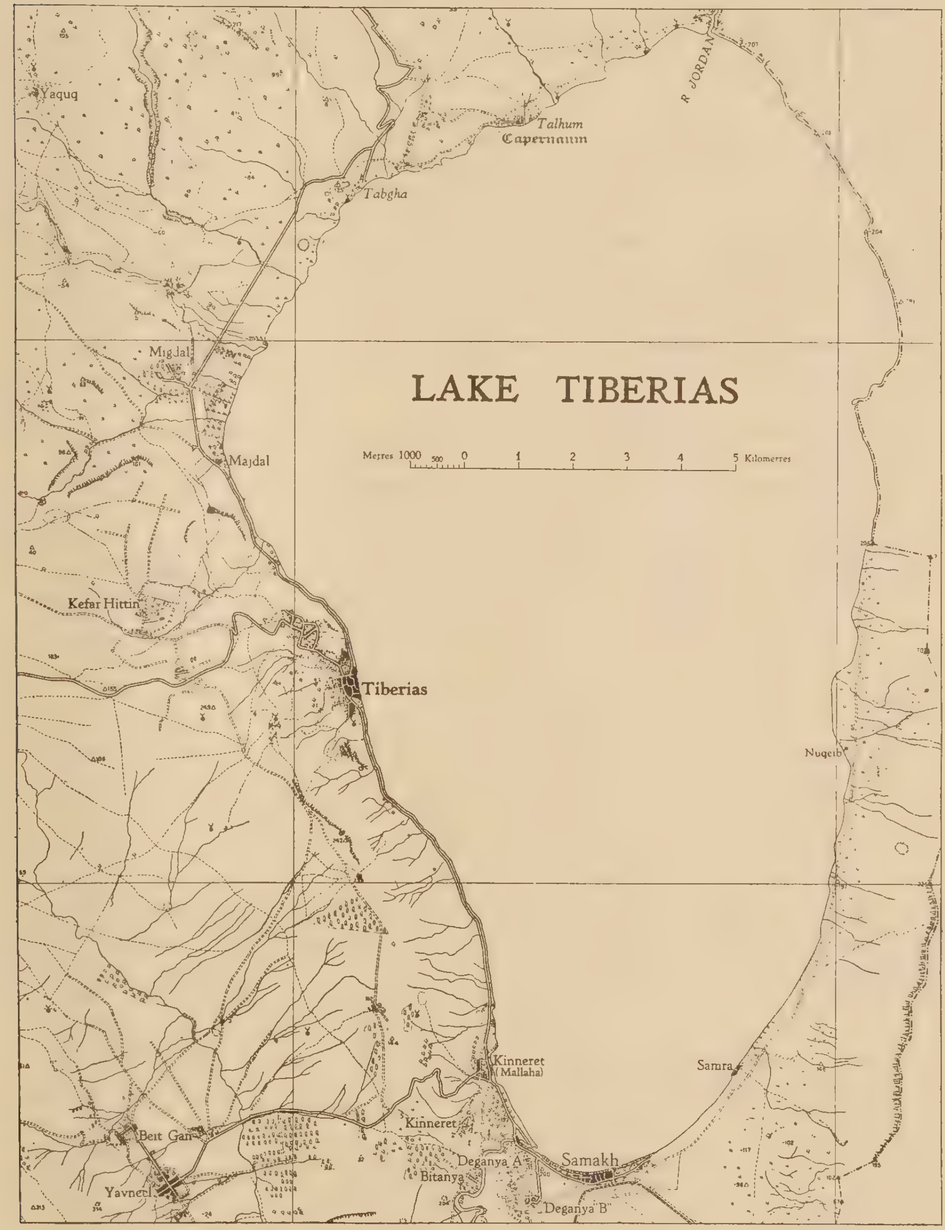
Yaquq
R JORDAN
Talhum
Capernaum
Tabgha
Migdal
LAKE TIBERIAS
Metres 1000 500 0 1 2 3 4 5 Kilometres
Majdal
Kefar Hittin
Tiberias
Nuqeib
Kinneret (Mallaha)
Samra
Kinneret
Beit Gan
Deganya A
Samakh
Bitanya
Yavneel
Deganya "B"

Fig. 3. Map of Lake Tiberias.

and Black Scale, leaves of the infested seedlings dropped. Seedlings which developed new leaves after defoliation became immediately infested with Black Scale. In this way during August–September the Black Scale succeeded in establishing itself on seedlings previously infested with Red Scale, the latter disappearing almost entirely from the seedlings, though it remained on the stems and twigs for several months. It should be mentioned that the second lot of seedlings infested with Red Scale (end March 1934) and placed in a corner of the insectary not very near to the Black Scale, suffered less from it, but the same process took place later (February 1935).

At Acre no thorough investigation of mutual tolerance of the scale was made. The following observations may be of interest in this connection. Red Scale was found in Acre (Stud Farm) in the following instances: On a few leaves and branches of unfumigated sweet lemon trees; on single leaves of carobs; on *Ligustrum* forming a part of the hedge of the Horticultural Station; on a number of trees introduced into the Citrus nursery from Italy; finally on trees brought from Mique-Israel Agricultural School. On the sweet lemon trees the Red Scale formed small islands among an extremely numerous population of Black Scale without propagating any further; these trees formed part of a Citrus garden. In the Citrus nursery and in the experimental plot of the Entomological Section Red Scale did not develop, though no control measures were undertaken.

8. Biology of Black Scale at Acre.

The seasonal history of the scale was studied at Acre in two ways: (1) By examination of a fixed number of leaves of different host-plants from each side of the tree every 10 days throughout the season; (2) by following the development on artificially infested seedlings in the field. Besides these a given number of fruits were examined regularly throughout their development.

This double investigation enabled a thorough study to be made of the yearly life-cycle, the death-rate and its causes, oviposition, and the activities of parasites and predators.

Succession of the generations.

At Acre the scale raises 3–4 generations, which are distinctly separated or only very slightly overlap in the later generations (the overlap being more accentuated in the month of October). The number, 3 or 4, depends chiefly on the average temperature of the spring and summer months. If the increase of temperature is normal and the summer heat starts in August (as usual in normal years), the spring and summer generations end late, leaving no time for raising a second summer generation, and the generation raised at the beginning of September has sexually mature females in the preoviposition period at the beginning of December or somewhat earlier. Few of these females (of the earlier hatchings) begin to oviposit, but the majority of them find in the second half of December such climatic conditions as to be compelled to pass into a long winter diapause. The progeny of the females which start ovipositing at the end of November all perish.

In a year in which the wave of warmth suddenly rises after the first weeks of spring or early in summer (end May beginning June), as was the case in 1934 and 1935, the periods of the spring and summer cycles are shorter, and the great summer heat allows an additional late summer generation.

In all cases the examination of picked leaves and the development on the artificially infested seedlings gave closely similar results. Temperature was found to be the factor of prevailing influence upon the duration of the life-cycle. Atmospheric humidity was regarded as of subordinate importance, as it was thought that under the shell there must be always a more or less unchanging amount of humidity, higher than that of the environment and uninfluenced by it, except in cases of the

" Khamseen " winds. These sirocco winds have been observed to have a detrimental effect on the larvae of Black Scale, especially after the first moult, killing nearly all of them. In an experimental infestation of seedlings in the field, on 10.iv.35, of 120 settled larvae all but two perished ; these two fell off in the pre-oviposition period without producing progeny. " Khamseen " winds lasted from 26th April to 3rd May, having maximum temperatures of 42–43·5°C. and a relative humidity very often below 25 per cent. These winds were also responsible for a sudden rise in the mortality of adult females in June and August 1934 (fig. 7, p. 707).

General features of a generation.

Each generation as studied in the material gathered in the field has the following features specific for the beginning, mid-course, advanced stage, and the end of the cycle.

At the beginning of an individual life-cycle we find : (1) a large number of " white caps," (2) a high percentage of living females ovipositing (up to 80 per cent.) ; (3) a low percentage of deaths in adult females ; (4) a high percentage of empty shells (abandoned by winged adult males).

The mid-course is to be recognised by : (1) a large number of nymphs after first moult ; (2) the decline of percentage of oviposition (about 50 per cent. of living females).

The advanced stage of the generation is indicated by : (1) the appearance of first adult females in the pre-oviposition period ; (2) presence of pupa stage in males ; (3) lowering of oviposition rate in females.

The end of the generation is shown by : (1) a lack of earlier nymphal stages ; (2) males are mostly pupae or winged adults, abandoning or having left their shells ; (3) either no oviposition or an extremely low percentage, *i.e.*, females of earlier hatches would be starting the new generation.

The spring generation starts with an oviposition of females, descendants of the late summer generation. These females come from two lines of development : (*a*) individuals which entered into the pre-oviposition period before the beginning of the rainy season (December) ; and (*b*) adults which were in December in the period after the first moult and passed through the second moult into the pre-oviposition stage only in the beginning or middle of March. Their numbers, however, are so low, owing to the influence of winter conditions and to the high mortality of settled larvae in March and April, that it is sometimes difficult to fix the exact date of the start of the spring generation. One fails in many cases to get an artificial infestation at this period under field conditions.

The spring generation is very limited and has a high mortality both in settled larvae and nymphs. The summer brood (July) is stronger and has a very low death rate in all stages. This enables the insect to strengthen its hold on the host-plant, to spread more widely, and to supply additional and more copious migrants to fruits which are just forming (the first migration to fruits starts with the spring generation in the second decade of April).

As the low death rate and steady increase in number continues throughout the summer (late summer generation), this part of the yearly life-cycle has to be regarded as the most dangerous to trees and fruits. At the end of summer (beginning of October) there is an abundant population of the Black Scale on the host-plants, and the species can now face the adversities of the winter climate without fear of being totally destroyed.

The mothers of the autumn–winter generation continue to oviposit up to (and a bit past) January, but the settling of the crawlers has never been observed after 15th December at the earliest, or 1st January at the latest. The mothers usually die after the first half of January. The few surviving up to March have dead, brown eggs in the body and dead eggs and crawlers under the shield.

An artificial infestation of seedlings of lemons kept under constant temperature (23·2°C.) and air humidity (60 per cent. R.H.) was started on 1.i.34 and produced the first settling crawlers on 16.i.34, *i.e.* 15 days after pinning on the infested leaves; so that the mother scales had to store a certain amount of temperature ($15 \times 23{\cdot}2$°C. = 348·0°C.) in order to enable the larvae to hatch.

TABLE VII.

Data of Generations in 1933/34.

Generation	Duration in days	Total temp. of generation	Average temp. of generation
		Degrees C.	Degrees C.
Spring	92	2095·0	22·7
Summer	50	1378·6	27·6
Autumn	230	4453·0	19·10
Grown in constant temperature ...	85	1971·5	23·2

TABLE VIII.

Data of Generations in 1934/35.

Generation	Duration in days	Total temp. of generation	Average temp. of generation
		Degrees C.	Degrees C.
Spring	81	1906·3	23·5
Summer	45	1291·2	28·7
Late summer	58	1539·6	26·2
Autumn–winter	190	3265·3	17·2
Infestation experimental plot	44	1267·4	28·7
Second generation	66	1665·3	25·2
Infestation of former experimental plot	57	1507·5	26·3

Yearly life-cycle in sun and shade.

The suggestion that Black Scale may raise in the sunny parts of the tree 1–2 generations more than in the shady parts of the same tree made necessary the study of this question. From the second decade of November 1933, up to the end of August 1934, ten leaves of orange were picked every five days, five from the north side in the densest foliage and five from the sunny part on the south-east, and an examination made as to the percentage of oviposition and the death rate of the adult females. The higher figure of ovipositing females was taken as indication of the earlier start of a generation. The results can be summarised as follows:

(1) The beginning of the generation is earlier on the sunny than in the shady part of the tree.

(2) When generation is at its height, *i.e.* in 15–20 days, the insects on the shady side make up this difference, and the rate of oviposition becomes more or less on a level with that in the sun or even higher.

(3) At the end of the generation the rate of oviposition is nearly alike on both sides and the percentages of living females in the pre-oviposition stage is the same.

These results show that even if the generation is earlier in starting in the sunny part of the tree there is no question of producing an additional generation as compared with the shady side, because for the development of the individual life-cycle the determining factor is not the microclimate of a special part of the tree, but the climate of the whole grove. The following table may serve as an illustration.

TABLE IX.

Showing Percentage of Oviposition of First Generation in Spring 1934.

Decade	Sun	Shade	Remarks
	Percent.	Percent.	
1. April ...	46·66	15·15	Start of spring generation, on 16.iv.34
2. ,, ...	47·70	33·3	
3. ,, ...	51·92	30·35	
1. May ...	53·44	40·00	
2. ,, ...	57·34	51·28	
3. ,, ...	6·6	2·1	
1. June ...	2·11	—	No evaluation of oviposition possible. More copious population in shade, though adult females more developed on sunny sides
2. ,, ...	—	—	
3. ,, ...	—	—	

The decline of oviposition from the 3rd decade of May has its cause in the fact that the progeny of the spring generation (future mothers of the summer brood) is now at the adult stage (pre-oviposition period) and that the adult females are going to die.

Acclimatisation of Black Scale from Migdal in Acre.

The infestation of seedlings with Black Scale from Migdal was done to test the development of the insect after fumigation. The results of these tests are explained further on. At the same time another problem was approached, namely, the behaviour of the scale transplanted from the hot climate of Migdal (Lake Tiberias) to the milder one of Acre. The material obtained from the Migdal scales was, however, too small to allow definite conclusions to be arrived at, and the explanations given here have to be corroborated by further tests of acclimatisation.

The infestation of seedlings and trees with Black Scale from Migdal was done at the same time as the infestation with Acre scales and gave two generations, one of longer duration (Migdal) and the other of shorter duration (Acre), all conditions of the plants being alike. The second generation of Migdal scales born in Acre behaved exactly like the indigenous Acre strain.

The only explanation of this fact is that the Migdal Black Scale on establishing itself in Acre takes longer to accumulate the warmth necessary to its development than in the place of its origin. The second generation, *i.e.* Acre-born scales from Migdal-born parents, fully adopts the behaviour of the Acre scales and has the same development and temperature requirements as the latter.

Development of Black Scale.

With the start of the spring generation on leaves in April there are still fruits in the Acre Sub-District, at the end of the cropping season, which here begins in mid-December and ends in the last days of April or the beginning of May. On these big fruits a spring generation arises like that on the leaves in the second decade of April and develops up to the middle of the first moult period at the end of the picking season. This brood does not contribute to the increase of the Black Scale population on the leaves and is mechanically interrupted by the picking.

The other fruits present are those just formed, which are of the size of walnuts. To them the first migration is observed at the end of April or beginning of May. However, these larvae coming from leaves do not raise a separate generation on fruits, and a second migration of crawlers of the July brood increases the population on the still small fruits. In August, when the settlers of the second migration have become adults and oviposit, the first "autochtonous" generation on fruits arises. This brood and that of mid-October (autumn–winter generation) swell the Black Scale population on fruits up to 80 per cent. and more of the crop, so that single fruits are sometimes entirely black.

Thus the fruits have two generations of their own, the late summer and autumn–winter generations, strengthened during all this period by additional migrants from the leaves.

The individual life-cycle of the insect on fruits is like that on leaves except that it is 5–6 days ahead. The oviposition rate on fruits is always higher than on leaves. Only in one case, when the increased activity of *Aphytis chrysomphali* destroyed 70–80 per cent. of all male larvae on fruits (October 1934) and a considerable number of females remained unfertilised, was there a lowering of the percentage of oviposition.

9. Biology in the Jordan Valley.

The activity of Black Scale is a function of different climatic factors and chiefly of temperature, high temperature being more important for its maturation than high humidity. In the case of normal development during the summer the pre-oviposition period of the female lasts approximately as long as all the preceding stages together, whereas in the winter generation the pre-oviposition period lasts only 43 days (half March and April), and the entire cycle up to the pre-oviposition period lasts more than 5 months or nearly four times as much (*cf.* fig. 2). The activity of Black Scale during the winter months (January, February) is minimal, then increases during the summer, and in the late summer reaches its maximum, coinciding with the maturation of Citrus fruits.

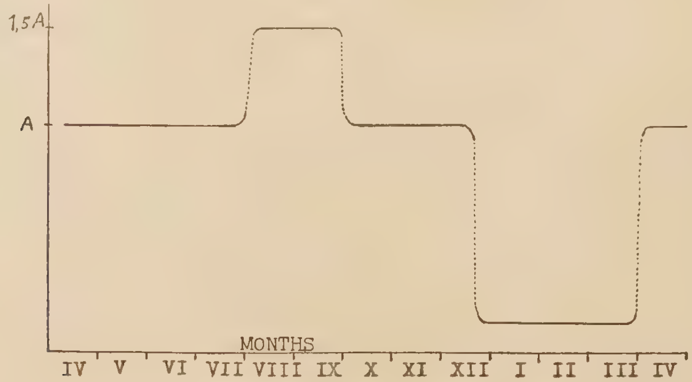

Fig. 4. Curve of Black Scale activity at Migdal (Jordan Valley).

In general, three periods were observed in the annual development of Black Scale at Migdal: (1) a period of normal development, in which the cycle from egg to egg is completed in about 60 days (April, May, June, half July); (2) a period of accelerated development, in which the cycle takes about 40 days (August, September), followed by another normal period (October, November); (3) a period of minimum activity, which if continuous would extend the cycle to about 300 days (latter half of December, January, February, and first half of March). Considering the development of Black Scale in 60 days as a unit of speed A, the accelerated development will give a velocity of 60/40 = 3/2 A, and the period of minimum activity a speed of 60/300 = 1/5 A. This permits us to construct the curve of Black Scale activity during the year (fig. 4).

The following table of artificial winter infestations in the insectary shows the gradual cessation of expansion owing to the decreasing temperature and the resumption of activity at the beginning of the spring, about the third decade of March.

TABLE X.

Table of Artifical Winter Infestation, 1934–35.

Date of infestation	Serial number	Result	General conditions
16.xii.34	17	Succeeded (19.xii.34)	Fine weather during and after infestation; S.E. wind. Settling relatively poor
23.xii.34	18	Succeeded (26.xii.34)	Heavy rains some hours after infestation, then fine weather; no wind. Settling poor
3.i.35	19	Partly succeeded (6.i.35)	Showers on the day of infestation; no wind; 4th and 5th January fine weather, then rain and strong S.W. wind. Ovipositing females withdrawn after 3 days. Settling very poor.
14.i.35	20	Practically failed (20.i.35)	Fine weather and S.E. wind on day of infestation. Many dead crawlers observed, settling extremely poor; practically this infestation = 0.
25.i.35	21	Practically failed (28.i.35)	Fine weather and no wind on day of infestation and the next; on 27th January S.E. wind followed by rains. Some isolated cases of settling observed
6.ii.35	22	Failed; only isolated cases of settling (18.ii.35)	Fine weather and no wind on the day of infestation. No settling was observed during the first 5 days; after 12 days poor settling observed
18.ii.35	23	Do. (24.ii.35)	Heavy rains during the first week after infestation
24.ii.35	24	Do. (28.ii.35)	No rain on the day of infestation, then showers and nice weather again
7.iii.35	25	Do. (14.iii.35)	Fine weather on the day of infestation and the following days
17.iii.35	26	Moderately infested, especially young leaves, old less so (21.iii.35)	Clouded sky, showers
25.iii.35	27	After 24 hours settling observed	Fine weather

It is proved by these observations that theoretically there was no absolute stoppage of reproduction during the winter, and this unusual condition also occurs naturally in the Jordan Valley, though not observed in other regions of Palestine, where there is a normal diapause ; but even under the most favourable conditions this activity is not sufficient for the spread of Black Scale and there is no noticeable expansion during the winter. This is explained by the fact that crawlers or settled larvae appearing during this time perish in enormous numbers owing to adverse weather conditions and only a small part of them survive. Practically only the first and second stage larvae and females of the pre-oviposition period are fit for hibernation. Females beginning to oviposit before the end of December rarely survive, neither do their offspring ; females beginning to oviposit after this period survive the winter, but their offspring perishes.

One of the problems arising in connection with Black Scale development was to find the exact starting-point of its activity, *i.e.*, the time when control should be the most efficient. In order to study this, artificial infestations were started on seedlings at different periods of the year. The interesting and important results of these infestations are summarised in Tables XI and XII.

TABLE XI.

Development of Black Scale in Insectary (Females).

Serial number	N1 Late summer	N2 Intermediate generation	N3 Intermediate generation	N4 Winter generation
Date of infestation ...	25.ix.33	6.x.33	24.x.33	16.xi.33
First moult—Began	6.x.33	15.x.33	5.xi.33	30.xi.33
Over	11.x.33	22.x.33	12.xi.33	10.xii.33
Second moult—Began	17.x.33	30.x.33	22.xi.33	10.ii.34
Over	22.x.33	8.xi.33	12.xi.33	12.iii.34
Preoviposition period	22.x.33– 25.xi.33 (35 days)	8.xi.33– 31.xii.33 (45 days)	12.xii.33– 25.iii.34 (100 days)	12.iii.34– 25.iv.34 (43 days)
Oviposition	25.xi.33– 15.iii.34	21.xii.33– 30.iv.34	25.iii.34– 1.v.34	25.iv.34– 10.vi.34
Total completed cycle	(60 days)	(70 days)	(150 days)	(160 days)
Death	End March 1934	End April 1934	Beginning May 1934	Beginning June 1934
Grand total	6 months	7 months	6·5 months	7 months

TABLE XII.

Development of Black Scale in Insectary (Males).

Serial number	N1 Late summer	N2 Intermediate generation	N3 Intermediate generation	N4 Winter generation
Date of infestation ...	25.ix.33	6.x.33	24.x.33	16.xi.33
Appearance of first males	31.x.33	9.xi.33	21.x.33	4.iv.34
Total completed cycle	(36 days)	(33 days)	(57 days)	(140 days)

Some explanations are necessary to these tables: The oviposition activity of series N1 and partly of N2 passed during the winter months, *i.e.*, the practical damage caused by the offspring of these generations in the infestation of groves was negligible. In the case of N4 oviposition began only in May; the mortality of this winter generation was considerable and therefore its activity was limited. It is chiefly the second half of October generation (corresponding to the fifth yearly Black Scale generation at Migdal) that is to be feared. The females of this generation passed the winter well and the death rate amongst them was low. Early in the spring (3rd decade of March) they began to oviposit; the females were very prolific (average about 160 eggs each) and the larvae were not exposed to any adverse conditions of weather.

The leaves of the infested seedlings of the series N3 were covered in April with a multitude of young settled larvae, which began rapidly to develop. The migration of crawlers to young fruits begins in the third decade of April, shortly after the fruit appears. The crawlers settling on fruit at this period are also chiefly the offspring of late October generations.

October and April should be therefore considered as the most important months in the Black Scale yearly cycle in the Jordan Valley, October giving rise to those generations whose oviposition and multiplication, in April and later, are responsible for the further infestation of the groves during the summer.

Cycle of generations and their number.

Owing to the permanent presence at Migdal of ovipositing females all the year round, causing overlapping of generations, it becomes very difficult in late summer to distinguish the numerical succession of the generations, as they are intercalated and not separated. Between the second and third generations or between the third and the fourth there are additional generations in which the time of oviposition does not coincide with that of the former. This overlapping is due to the fact that the oviposition period of a single female may last from some weeks to some months, which explains why during the summer months all stages of Black Scale (eggs, larvae of different ages, and adults) are met with, so that it is more exact to speak of series of generations (*e.g.*, October series of generations, etc.) rather than of a numerical succession of them. This prolonged oviposition period should be of great advantage to the species, as the young and unprotected larvae are not exposed simultaneously to external conditions that may be adverse to them.

There are five full generations of Black Scale during the year at Migdal. Observations on the number of generations during 1933–34 were made on fruits in the groves; the method employed was as follows: In the spring some fruits displaying larvae of the "white cap" stage (*i.e.*, about 1–2 days old) were bagged and remained under observation till the oviposition of the females; then 2–3 days after the first case of oviposition was observed and when this became general, all scales of different ages on the fruit were withdrawn, leaving again only crawlers or white cap larvae. This was repeated with every generation all the year round. During the year 1934–35 the method applied was slightly changed. The observations were made in the insectary, where seedlings were artificially infested in the third decade of March 1934 (beginning of full activity of the scale), then when the females began to oviposit further seedlings were artificially infested, giving thus the natural continuation of the previous generation. This was repeated for every new generation all the year round, the results in both cases being the same. The duration of the life-cycle (from egg to egg) of every one of the generations changes with the season from a minimum of 40 days for a ♀ and about 26 for a ♂ to 160 days for a ♀ and about 140 for a ♂.

The graph of Black Scale generations as observed at Migdal during the years 1933–34 and 1934–35 are shown in fig. 5.

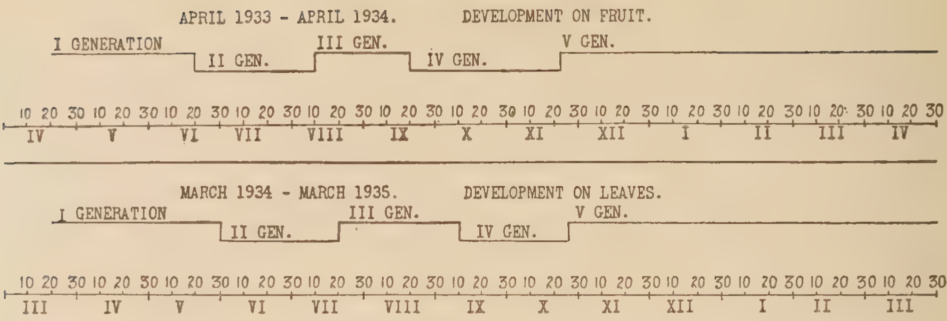

Fig. 5. Graph of Black Scale generations as observed at Migdal in 1933–34 and 1934–35.

10. Influence of Climatic Factors on Development.

It has been already observed that temperature is the factor which is to be regarded as having most influence on Black Scale development, being much more important than relative air humidity.

Comparing the life-cycles of Black Scale in Acre and Migdal we see that the number of generations is higher by 1–2 broods in the Jordan Valley than in the Coastal Plain. This is due to the hotter climate of the Jordan Valley, which has a yearly average of 22·5°C., whilst in Acre the average reaches only 19·3°C.

The secondary importance of air humidity is, on the other hand, indicated by the fact that the higher humidity in the Coastal Plain does not produce an increase in the number of generations there, which are fewer than in the Jordan Valley, where a constant low relative humidity prevails throughout the hot summer months.

In the Jordan Valley the R.H. during the summer is in the vicinity of 50 per cent. (and even less) after 8 a.m. and until evening : a slight increase is to be observed during the night, attaining its normal maximum at 60–65 per cent. No 100 per cent. saturation, and consequently no dewfall, is to be noticed all the summer.

It may be remarked that the area of Black Scale infestation is not limited to the short radius of Lake Tiberias, as areas beyond its tempering influence, such as Yavneel Colony (Tiberias Sub-District), have a considerable population of Black Scale besides a very heavy incidence of Red Scale.

In the Coastal Plain of Acre the humidity conditions are distinctly different from those described above. The R.H. in the months of June to September is in the vicinity of 60 per cent. at 8 a.m. with a dew-fall, very often a heavy one, from 9 p.m.

All our measurements have been taken in screens. It must, however, be kept in mind that the microclimatic conditions of air humidity under and inside the trees are slightly different from those in a screen, the R.H. increasing beneath and inside the tree owing to the transpiration of the leaves and as a result of irrigation, and is influenced also by the spacing and age of the trees. The reason why the relative air humidity has little influence on the development of the scale may be looked for in the presence of a hard shell protecting the insect and allowing it to gather a somewhat higher amount of humidity than that available in its immediate surroundings. If the reverse were true, the Khamseen winds with a temperature of 43°–44°C., and sudden drop of R.H. of 20 per cent. would cause a much higher mortality of Black Scale adults than was observed in these cases.

Far more important than conditions of air humidity are the conditions of food supply available for the scale-insects settled on the leaves and fruits, as on Khamseen days the quickly evaporating leaves compensate their loss by a quicker circulation of sap. This also explains why under-watered trees in areas with high R.H. (Coastal Plain) have a low population of scale-insects.

11. Threshold of Development.

In the course of these investigations an endeavour was made to express the development of the insect in a mathematical formula which would reflect the dependence of the duration of the developmental cycle on temperature.

Such a formula is given in Blunck's equation of the threshold of development. This formula $C = A(TA\text{–}TO)$ signifies that the individual life-cycle of an insect needs for its completion a certain constant amount of temperature (C) which is the product of the duration of the cycle (A, B) and the difference between the average temperature of the cycle (TA or TB) and the zero or threshold of development (TO). The threshold of development is the temperature under which no further development is possible and at which the insect remains in a diapause.

In order to find this threshold two life-cycles of the insect must be known. If for example $C = A\ (TA - To)$ for one generation, so will $C = B\ (TB - To)$ for another generation. The equation is

$$\begin{aligned} A(TA - To &= B(TB - To) \\ ATA - ATo &= BTB - BTo \\ To\ (A - B) &= ATA - BTB \\ To &= \frac{ATA - BTB}{A - B} \end{aligned}$$

ATA, BTB, sums of temperatures for the respective cycle are the sums of average daily temperatures during the cycle without taking into account minima and maxima.

The zero point of development of Black Scale for Acre is found to be 16·9°C. and the thermal constant (C) 535°C. on the basis of the following data:—

1. *Spring generation* 1933 = 92 days duration.
Total Temperature = 2095·0°C., average temperature 22·7°C.

2. *Summer generation* 1933 = 50 days duration.
Total Temperature = 1378·6°C., average 27·6°C.

$$To = \frac{2095{\cdot}0 - 1378{\cdot}6}{92 - 50} = \frac{716}{42} = 17{\cdot}0°\text{C}.$$

The zero point 17·0°C. is to be corrected to 16·9°C., which is the average of evaluation of figures between 16·8–17·1°C.

Thermal Constant (C) =

$$\begin{aligned} 92\ (22{\cdot}7 - 16{\cdot}9) &= 50\ (27{\cdot}6 - 16{\cdot}9) \\ 92 \times 5{\cdot}8 &= 50 \times 10{\cdot}7 \\ \underline{533{\cdot}6} &= \underline{535} \end{aligned}$$

For Migdal the evaluation is different as explained in the following.

1. *Winter Generation* 1933/34 = 160 days duration.
Total Temperature = 2556·5°C., average temperature 16·0°C.

2. *Spring Generation* 1934 = 60 days duration total temperature 1467·8°C., average temperature 24·5°C.

$$To = \frac{2556{\cdot}5\ 1467{\cdot}8}{160 - 60} = \frac{1088{\cdot}7}{100} = 10{\cdot}9°\text{C}.$$

Thermal Constant (C) for Migdal =

$$\begin{aligned} 160\ (16{\cdot}0 - 10{\cdot}9 &= 60\ (60\ (24{\cdot}5\text{–}10{\cdot}9) \\ 160 \times 5{\cdot}1 &= 60 \times 13{\cdot}6 \\ \underline{816} &= \underline{816} \end{aligned}$$

The divergence between the dates does not permit of any definite conclusion. The attempt to make the figures conform did not give the results hoped for. This cannot be due to any error in evaluation, the same methods having been employed as in reckoning the formula for other insects. It has been thought that these discrepancies may be chiefly due to the fact that the Black Scale of Migdal and of Acre are of different thermal races, *i.e.*, that the latter needs to accumulate a lower amount of warmth in order to complete its life-cycle than does the former.

This opinion seems to be confirmed by trials of acclimatisation of Black Scale from Migdal in Acre, in which the first generation (Migdal-born crawlers settling on Citrus in Acre) have a more prolonged life-cycle than the control generation (Acre-born crawlers) ; only the second generation (Acre-born scales of Migdal-born parents) adopted the features of the Acre scales, so that the second generations were alike. (See 8. Biology of Black Scale.)

A possible explanation is that the Migdal Black Scales are of a different thermal race, accustomed to concentrate a higher amount of temperature for the completion of a life-cycle. The study of this question will be continued by further acclimatisation experiments.

12. Effects of Manure and Irrigation on Infestation.

A series of observations on Black Scale infestation on Citrus and other host-plants suggested the idea that the food and water supply to the tree may have an influence on the amount of infestation.

The Eucalyptus grove at the Government Stock Farm Agricultural Station at Acre covers an area over 300 dunams, but only scattered groups of trees exhibit moderate to heavy infestation, whilst the bulk of the grove is free from Black Scale. It is noteworthy that the scale is not progressing in this grove, though no control measures could be taken even if such progress were noticed.

Acacia and Washingtonia trees are heavily infested in the Poultry Station of Acre, whilst other trees of the same species in other places on the Stock Farm are free from the scale. Bananas forming a border to a heavily infested orange grove near Acre and only 3 metres distant from the infested Citrus trees are clean. Myrtle trees have been seen heavily infested and others clean during 3 years observation in a private garden containing 40 Citrus trees with excessively heavy infestation and unfumigated for a period of six years.

The fact of Black Scale thriving better on one group of a host-plant than on another in the same area suggests that the cause must be looked for in the excess of concentrated food or irrigation supplied to the plants. The richly populated trees of Acacia, Washingtonia, and Eucalyptus, at Acre Poultry Station, are those that are in the pens in which the manure of fowls is lying freely under and round the trees.

The above-mentioned bananas forming the border of a Citrus grove are not included in the plot but grow on its edge, and their food supply is by no means so rich as that of the orange trees in the vicinity. In the above-mentioned garden in Haifa myrtle trees included in the plot are those which display a heavy infestation ; they are cultivated and irrigated like the Citrus trees, whereas those bordering the path of the garden are left without any cultivation and are free from the pest.

The higher rate of food and water makes the sap of the tree richer and more attractive for the scale. Poorly cultivated Citrus (and other) trees incline to establish a poor Black Scale population.

Similar observations were made in the Jordan Valley (Migdal). Trees in the vicinity of an irrigation plant showed a bad infestation, though others at some distance were clean. All these trees form a grove and were fumigated on the same day, and there was a good kill of the scale on all of them. The richer food and water supply is to be regarded as one of the chief factors favouring Black Scale infestation.

13. Individual Life-history of Black Scale.

Oviposition.

The Black Scale is an oviparous species, and no departure from oviparity has been observed.

The egg is oval in shape, small, about 0·25 mm. and of a lemon-yellow colour. The embryo is enveloped in a chorion, a white thin and transparent membrane. After the hatching of the " crawler " the chorion remains under the maternal shield, and there can be seen a big agglomeration of egg-shells at the end of the oviposition period. The number of eggs a single female lays during 24 hours is not large in general and varies considerably during different periods of the year.

The act of oviposition occurs at irregular intervals even during the same season, varying from half an hour to several hours during the summer and once or twice daily during the winter. The average number of eggs laid by a single female during 24 hours was 5–6 in summer and 1–1·5 in winter (Migdal). At Acre after the middle of January no oviposition was observed until the start of the spring generation in April, the adult females being in a winter diapause. The maximum number of eggs laid observed at Migdal per female and per 24 hours was 19 (1.x.33), but this figure must be considered as an exception.

The small fluctuations of daily temperature do not influence oviposition. The maximum number of eggs that can be found under the female shield is about 25 during summer and about 10 in winter, but usually during the summer this figure is lower. It takes the eggs 1–4 days to produce larvae at Acre, whereas the time at Migdal scarcely exceeds 2 days (summer). The period between oviposition and the emergence of crawlers is prolonged in late autumn and early winter up to 7–10 days under field conditions (Acre).

At Migdal oviposition was observed throughout the year; there was no time when females were not able to oviposit even after unusual falls of temperature in the Jordan Valley (minima of 2·5°C. and 3·5°C.).

Observations on the ovipositing capacity of a single female on leaves and fruits in groves, in the insectary and in the laboratory, in both Migdal and Acre, were made at different periods of the year. An average number of 150 eggs per female during the oviposition period may be considered as normal. The maximum number of eggs per female observed was 211 (Migdal) and 247 (Acre). No noteworthy difference in the number of descendants was observed in shade and in full exposure to sun.

Hatching and Crawlers.

The newly hatched crawler is of the same size as the egg, oval in shape and yellow, with rather short, distinctly segmented antennae. During the hot season hatching is completed in a single day or even less (sometimes in a few hours, Migdal). The crawler remains still for 1–2 hours, after which it creeps about for 6–8 hours before it finally stops and prepares for settling. The period is much longer when the temperature decreases. At Migdal, where oviposition was observed throughout the winter, eclosion is extremely slow at this season and only a small percentage of eggs hatched.

In January and February eggs took 5–6 days to hatch (Migdal laboratory). Crawlers were often observed in a half-hatched state for several days, being unable to free themselves from the egg-shells. The crawlers in winter remain in a state of apathy for a week or more after hatching, giving the impression of being numbed with cold, so that it is very difficult to discern whether they are alive.

In general, the mobile stage is of short duration as compared with the total longevity of the insect, and the shorter this period is the better for the species, as the crawler is the stage most exposed to external dangers. It is difficult to evaluate the extent of the natural mortality of the crawlers, but it is clear that extremes of temperature are the factors chiefly responsible. A temperature of 25–30°C. is favourable for their development, whereas Khamseen winds with high temperatures of 40–45°C. and the drop of temperature in January and February destroy them in large numbers. They remain without food till their fixation, failing which they will die in a few days.

Settled larvae and adults.

After settling, the female passes through the following stages : 1st and 2nd larval moults and the preoviposition and oviposition periods. The duration of each of these stages is a function of the temperature. As soon as the crawlers settle the secretion of wax begins ; this looks like a white film which becomes compact and forms in one to six days the so-called " white cap " stage. During the time following the fixation of the crawlers till the first moult no changes except the development of the proboscis are to be observed. The larvae retain their legs and antennae, but their movements slow down and soon cease. The first moult begins about 7 days in summer and 15 or more in winter (Acre early winter) after fixation. It is marked by the appearance of a ring in the upper part of the " white cap " covering ; the legs and antennae disappear and the larva becomes circular, with a clearly visible pygidium.

The shield of the larva at the beginning of first moult consists of three rings with a white knob-like point in the centre. The colour of the shield of this period is reddish brown with a broad grey edge. The first moult is completed in 5–6 days during the hot season in the Jordan Valley. At Acre this process is somewhat longer, lasting 7–15 days according to temperature conditions. Immediately after the completion of the first moult no specific sexual characters can be seen. It is somewhat later that the shell of the male larva gets its dark ring. The male larva itself becomes more elongated than the female, and develops shallow longitudinal furrows on the back and the contours of a pair of eyes. It is attached to the leaves or fruits by means of the proboscis and has no ventral skin. The pygidial characters are still alike in the two sexes.

After an interval of 6–8 days in summer (Migdal) and 12–15 days in Acre and much more in winter (about 2 months) a thin membrane appears on the ventral face of the female larva (as in the case of the first moult), and the second moult begins. At the beginning of the second moult period the shell shows three rings at the centre : a white ring with a dark point inside it, a reddish brown ring and a broad ring ending with a broad grey fringe. The fringe extends beyond the body, thus giving the insect the opportunity of further growth until it enters the pre-oviposition stage. After 5–7 days in summer and about 30 days in winter the second moult is completed (Acre and Migdal). During the first and second moults the ventral membrane of the larva is closely associated with the dorsal shield and the extraction of the insect is impossible at this period. It is quite probable that the moult periods of the Black Scale are more resistant to fumigation, as Quayle suggests in the case of the Red Scale, as the penetration of the gas is more difficult and the respiration of the insect is lowered. After the female's second moult the pre-oviposition period begins, which is characterised by the growth of the insect and the change of colour from greenish to deep yellow.

At the very beginning of the pre-oviposition period squeeze preparations of young females show a hyaline-yellow mass with many threads in it but no sign of eggs. Then 18–20, later 40–50 and 50–130, eggs are to be counted under the microscope before oviposition has begun. The pre-oviposition period lasts about 25–30 days during summer.

The shield of the female adult is circular, convex, and varying in colour from deep black to violet black and sometimes brownish black. At that period a specific displeasing smell appears, which is striking when Black Scale is in large numbers in infested groves. The total longevity of the female extends from 3–4 months in summer to 6–7 in winter.

Cycle of male.

After the first moult the male goes through two additional moults, passing into prepupal and pupal stages; the total number of moults is thus four, the last one on entering the winged stage. The shield of the male larva begins to elongate and its form is determined before the larva reaches the stage of prepupa.

The puparium is oval in shape, black with a dark grey posterior extension. The prepupa is characterised by the appearance of imperfect antennae and two small appendices on the pygidium and by the first contours of the wings. The body is of a brownish-yellow colour. The pupa has two lateral sheaths attached to the body (future legs) and wings in shape of white crumpled veils. At the end of the abdomen a spiculum (the male sexual organ) appears between two appendages.

TABLE XIII.

*Number of Progeny produced by individual Females at Acre.**

No.	Date of bagging	Date of removal	Leaf or fruits	Females	Males	Total
1	27.v.34	27.vii.34	Leaf	99	56	155
2	,,	,,	Leaf	85	55	140
3	19.vii.34	27.ix.34	Leaf	129	37	166
4	,,	,,	Leaf	84	40	124
5	,,	,,	Leaf	56	63	119
6	,,	,,	Leaf	105	132	237
7	30.ix.34	29.xi.34	Fruit	126	121	247
8	19.xi.34	19.xii.34	Fruit	66	49	115
9	29.x.34	28.xii.34	Leaf	78	46	124
10	,,	,,	Leaf	68	42	110
11	,,	,,	Leaf	84	58	142

* Females that were unfertilised or died before giving birth to all their progeny are not recorded (9 cases).

The development of the male is accomplished in a much shorter time than that of the female. As the female is ready for copulation shortly after the second moult the males of the same generation emerge at the beginning of the female's pre-oviposition period. The males do not take any food, their mouth-parts being completely atrophied, and they could not be kept alive in test-tubes more than 2–3 days, so that during the hot period of the year the total longevity of the male does not exceed 40 days. During the winter the cycle of the male was completed in 140 days at Migdal and 160 at Acre.

The males, as mentioned before, prefer always to settle on the upper surface of the leaves in relatively large colonies. The proportion of males is about 40–50 per cent. of the total population; in the late summer generation they are somewhat more numerous.

Reproduction.

The question of parthenogenesis was investigated on a small scale in the laboratory at Migdal, on a larger scale at Acre, and gave a clear negative result as to the possibility of females of Black Scale producing offspring without the aid of males. Isolated and bagged females which remained unfertilised formed the eggs in their body as usual, but after a short time fell off the leaf or died ; whilst females bagged with male larvae accomplished their full cycle in accordance with the development of the scale under field conditions. Three tests were made, each of twenty Citrus seedlings with an approximate number of 100 females per seedling. Males in the stage of prepupae were cleaned off four times before the final bagging of the females. As in the case of Red Scale, copulation is probably nocturnal, as it was never observed during the day.

Mortality of full-grown females.

Examining the mortality of full-grown Black Scale females during the winter we get the impression that it is lower than during the summer. This is explained by the fact that the dead scales during the winter are washed off by the rains, the majority of the remaining scales being alive ; while during the later summer there is an accumulation of dead scales from many generations among the living scales of only one generation, thus creating the impression of very high natural mortality of full-grown female scales.

In reality, in the female scales after the second moult the natural mortality is low and chiefly due to age ; a not insignificant percentage is killed by *Chilocorus bipustulatus* in late winter and up to May, and a small number perish owing to the high temperatures of the Khamseen winds. Full-grown females were never killed by minimum temperatures.

The accompanying graph (fig. 6) shows clearly that there is no overlap in the generations in Acre, except in the autumn–winter generation. The low records in

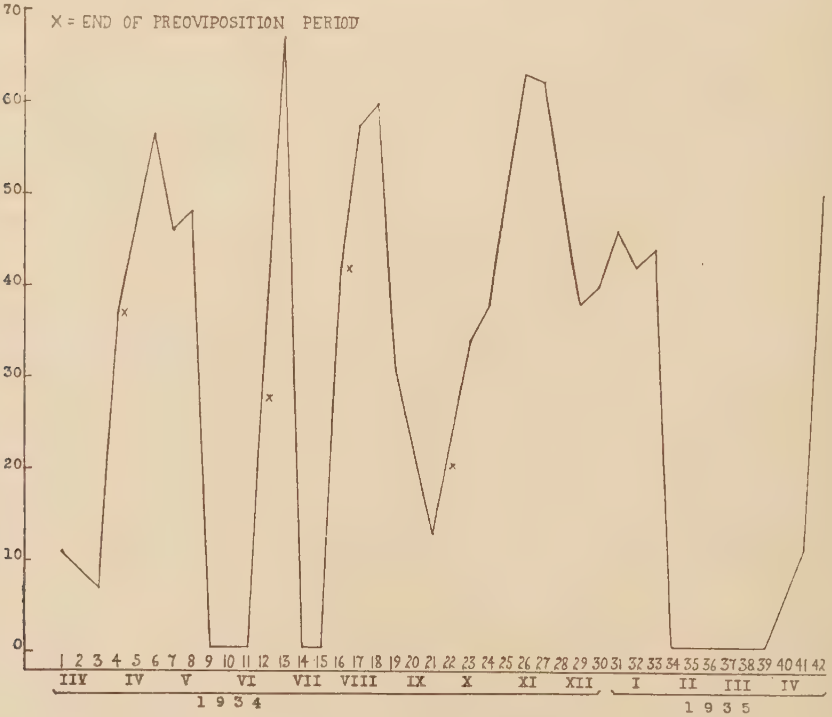

Fig. 6. Oviposition of *Chrysomphalus ficus*, Ashm.

February, May–June, and July 1934, indicate pre-oviposition periods, during which most of the adult females had not yet started laying. The low level in February–March 1935 represents a diapause in the adult females and female nymphs.

The natural mortality of adult females and female nymphs is shown in another graph (fig. 7). The mortality is normally low, but rises slightly at the end of a generation and still more in the middle of winter. The exceptionally high death rate in the larvae from February to April 1934 was due to climatic conditions during the first half of this period, and in the second half to the accumulation of dead scales over a long period. The rise of mortality in April 1934 is accounted for by the activity of of predators ; that of May and July 1934 was due chiefly to Khamseen winds.

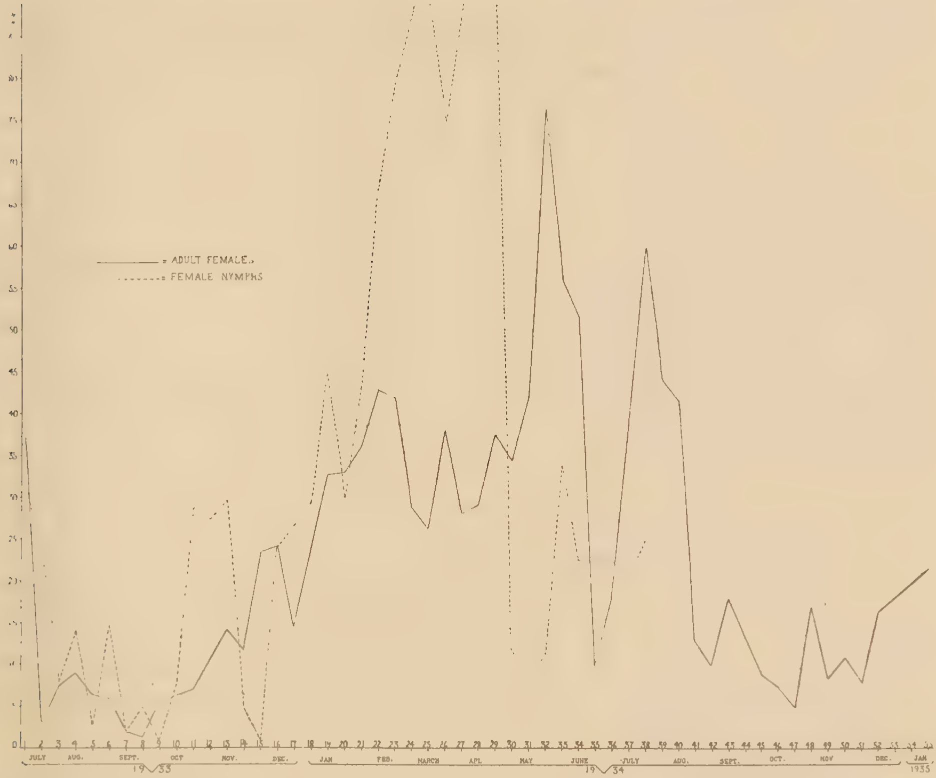

Fig. 7. *Chrysomphalus ficus*, Ashm., mortality of adult females and female nymphs.

14. Enemies and Control Measures.

Parasites and predators.

No parasites of female Black Scales have been observed in Palestine, except in two instances, during two years' observations, and these cases were most probably accidental. On the other hand, the larval stages of the males after the second moult are parasitised by a Chalcid, *Aphytis chrysomphali*, Merc., but the percentage of parasitism varies considerably as between the Jordan Valley and Acre. In the Jordan Valley it is low; at Acre the parasitism is higher from October to February or March and low during the hotter period of the year. The percentage of parasitism for Acre is given in the attached diagram (fig. 8).

The economic importance of *Aphytis* is limited, being only of biological interest. The causes of this are to be sought in the short life-cycle of the Chalcid, to the non-coincidence of the maximum activity of the host and parasite, and to the irregularity of the parasitism. During the spring and summer months the parasite often comes to a standstill owing to not having hosts enough on which to oviposit, so that its numbers become greatly reduced.

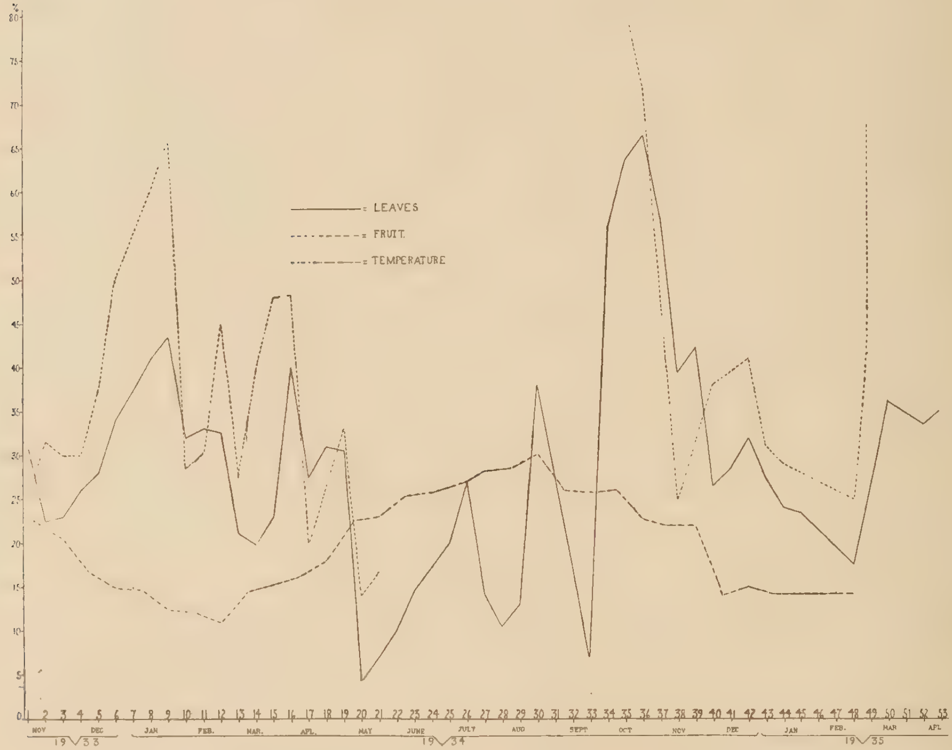

Fig. 8. Parasitism of male nymphs of Black Scale (*Chrysomphalus ficus*) by *Aphytis chrysomphali* on leaves and fruit in relation to temperature.

In the autumn and winter months, however, during which it takes the Black Scale male larvae much time to develop into pupae and prepupae, the more rapidly reproducing parasite always finds suitable stages of the host for oviposition and development. This, and the fact that only the male scales are parasitised, makes the Chalcid a factor of secondary importance and ranges it as only one of the many causes restricting the development of the scale.

As to predators, the Coccinellid, *Chilocorus bipustulatus*, is to be mentioned as occurring in all Citrus belts in great numbers, both the larvae and adults feeding on various Coccids, including the Black Scale. The larvae of another small Coleopteron of the family Clambidae were observed at Migdal feeding on eggs of Black Scale, but the species has not yet been identified. Its checking influence upon Black Scale is still more restricted than that of *Chilocorus*. A Neuropteron (Chrysopidae) is met with in small number in the groves during April–May, but there is no certainty as to its importance.

The occasional fungi observed on Black Scale are all of them saprophytes and without any significance. So it becomes clear that owing to the absence of a parasite of the females, the restricted rôle of *Aphytis chrysomphali*, the insufficient activity of predators, and the lack of entomogenous fungi, the only way of controlling Black Scale is by chemical treatment or by the introduction of a really efficient parasite.

Spraying.

Experiments were made with two proprietary oils at Tabgha (Jordan Valley) in June and August 1933 and were under observation until June 1934; these observations are summarised in fig. 9. An examination of the figures received proves that about three months after the double treatment the mortality of Black Scale rose to 45 per cent. and 35 per cent. for oils A and B, respectively, which is equivalent to a reinfestation of the fruit before and during the picking season.

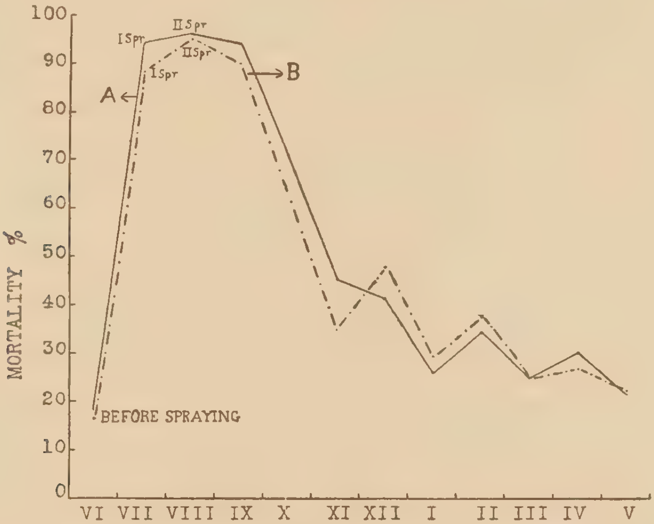

Fig. 9. Percentage of Black Scale mortality at Tabgha grove during 1933–34, before and after spraying with two proprietary oils, A and B.

Further observations on spraying at Migdal during the summer of 1934 in different groves prove the inefficiency of this method, the reason being the high cost and the low killing power of the single spray (60–70 per cent. of kill).*

Taking into account the number of generations during the year, the short time needed for the completion of development, and the high reproductive capacity of the female, no treatment giving a kill below 96–100 per cent. is worth consideration.

Spraying, however, can be of some use as an auxiliary treatment after fumigation, when during the summer small centres of reinfestation appear. Such centres should be treated immediately, as they are a latent danger for the groves.

Fumigation.

The evaluation of the efficiency of fumigation at Migdal was rendered possible by a survey of picked fruit during the exporting season of 1933 and 1934. The attached Table XIV gives the results of such an examination of fruit from nine groves for the year 1933. The figures in this table proved that in the case of a satisfactory kill the

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* The high percentage of survivors after spraying in summer is due chiefly to the frequent occurrence of cobweb on the lower side of the leaves, under which the scales remain sheltered.

TABLE XIV.

Number of grove	Kind of fruits	Degree of infestation before fumigation	Date	Fumigation method	Percentage of kill	Fruit picked	Percentage of cull due to scale	Remarks
N1	Lemons	Medium	10.vi.33	Sulphuric acid (pot method)	100·0	25.ix.	5·0	Examined 1,000 fruits
N2	Grapefruit	Medium	31.v.33	Cyanofumer	97·74	3.x.	10·0	From the total crop
N3	Grapefruit	Medium and heavy	4.vi.33	Cyanofumer	100·0	3.x.	2·5	Examined 1,400 fruits
N4	Grapefruit	Medium and heavy	4.vi.33	Cyanofumer	100·0	3.x.	1·3	From the total crop
N5	Grapefruit	Medium	10.vi.33	Sulphuric acid	100·0	8.x.	3·5	
N6	Grapefruit	Medium	25.vi.33	Sulphuric acid	98·55	22.x.	11·0	From the total crop
N8	Grapefruit	Medium	21.v.33 & vi.33	I Cyanofumer II Bisulphate	100·0	13.xi.	1·0	From the total crop. Grove refumigated
N9	Grapefruit	Medium	22.v.33 & vi.33	I Cyanofumer II Bisulphate	100·0	10.xi.	2·0	From the total crop. Grove refumigated
N10	Grapefruit	Heavy	23.v.33	Bisulphate	28·36	14.xi.	26·8	

average percentage of the cull caused by Black Scale reinfestation at the end of the season fluctuated between 2 and 12 per cent., which was then considered a good result.

The fumigation results for 1934 were in general better than those for 1933. In many groves the fruits were quite clean till October; generally the amount of reinfested fruit rarely exceeded 5 per cent. of the total crop, being often below this figure; there were, however, one or two exceptions with 15–20 per cent. reinfestation. It becomes evident that by a regular fumigation practice the amount of reinfested fruit should in future not exceed 5 per cent. of the total yield during the picking season.

Taking into account that the amount of infested fruit in unfumigated groves at the end of the summer is about 70–80 per cent. we can consider these results as more than satisfactory.

Very good results were obtained in the case of winter fumigation both at Migdal and Haifa. At Migdal during the first eight months after fumigation the trees remain practically clean, and at the end of the year they were moderately infested. The mortality of scales in winter fumigation was near 100 per cent., as observed twice (December 1933 and January 1935). The lack of fruits in the groves at this period is also of importance; generally the picking season in the Jordan Valley is over in December.

In Haifa the effect of winter fumigation was kept under continuous observation during two years in the case of the German Hospice Citrus garden. Fumigation was done on 26th December 1932, and was followed by heavy leaf-fall. During the first year after fumigation (1933) the trees employed their sap for the formation of new leaves and had no buds. The leaves were clean, with exception of those on three badly fumigated trees in a corner of the garden. In July 1934 the reinfestation began; this was going on slowly up to May 1935, and at the time of writing the grove shows a full reinfestation. The fruits of the cropping season of 1934 were quite clean, and the mandarine trees were observed to be clean even in the last inspection (June 1935).

Eradication treatment.

Possibilities of eradication treatments for Black Scale based on biological data were taken into consideration for both Acre and the Jordan Valley. The situation being dissimilar in the two areas, no common lines of procedure can be laid down. In the Jordan Valley two fumigations, one in March and the second in October, could be suggested as an eradication treatment. As the middle of March is the period of blossom and in October the fruit is beginning to turn yellow, this double fumigation can be applied only in case of non-bearing groves.

As to normal groves such treatment would be unreasonable, and the proper time for fumigation is as early in the year as possible, according to the size of the fruit, *i.e.*, at the beginning of May if summer fumigation is practised; otherwise the tendency is towards winter fumigation. Then the percentage of kill will be good (the migration of crawlers to fruit begins in the third decade of April) because the fruits are still clean, and expenses for cleansing infested fruits from killed scales would be saved.

In the Acre area double fumigation applied during the summer can be suggested as a more or less full control of the pest. The idea is based on the following consideration. As the second summer generation is that which establishes the Black Scale in masses on the leaves and strengthens the population on the fruits, the control has to aim at breaking two links in the yearly cycle at critical points, *i.e.*, in the pre-oviposition periods of the two summer generations and in the pre-oviposition period of the autumn generation. Thus two fumigations would have to be carried out in one year, which should leave the trees clean for a period of at least 3–4 years.

This scheme is now under experiment in a block of 1,000 trees in the Bahja grove, Acre. The results of the double fumigation will be checked and published in due course.

Problem of fumigation survivors.

Does any change occur in the activity of female scales surviving fumigation and especially in the offspring of such females?

To study this problem artificial infestations with offspring of surviving females were tried on both fumigated and unfumigated trees. It was thought that on the leaves of fumigated trees some of the poison might remain and thus influence to a certain degree the further development of the scales.

At Migdal, seedlings and trees were infested in both the insectary and the groves, and at Acre seedlings only, with the offspring of fumigation survivors. The infestation succeeded in all cases. That at Migdal was done with leaves from a grove displaying a mortality of 88 per cent. after fumigation (Acre 85 per cent.).

The first generation completed its cycle during the same time as a generation of normal scales; the second generation (offspring of the previous one) also behaved like the corresponding generations in the insectary where no fumigation took place. As to the ovipositing capacity of fumigation survivors, no changes were observed. The average number of descendants per female was 105·7, with single females giving about 150 settled larvae. The case of a surviving female that produced 232 settled larvae at Acre was specially remarkable. These observations prove that the vitality of descendants of fumigation survivors is not lessened in any way.

In the case of fumigated groves the reinfestation is to be attributed to the activity of fumigation survivors on the spot, and to a much less extent to migration of scales from other groves and plants.

15. Observations on Aphytis chrysomphali.

The adult of *Aphytis chrysomphali* emerges head-first, lying on its back, from under the grey prolongation of the shell of the Black Scale male prepupa or pupa. It leaves behind the pupal skin and 5–8 black ovoid bodies (excrement) under the shell. The presence or absence of the excrement serves to indicate whether the male scale has been parasitised or not. The adult of *A. chrysomphali* never bites a hole in the covering of the male scale, and if such a hole is observed it has been caused by *Chilocorus bipustulatus*, which attacks both males and females.

Most of the insects kept under observation were females; its seems that males are very restricted in numbers in the population of *A. chrysomphali*.

Oviposition.

Oviposition was never observed in female scales and no larvae or pupal stages of the parasite were found.

The female of *Aphytis* is apparently attracted by smell to the males of Black Scale. It takes some time for the parasite to decide which of the many scales to choose; it palpates them with the antennae, finally twists the abdomen on the sloping side of the covering, and leaning on the hind legs pushes the ovipositor through the shield. All the body quivers with the effort of the act. Oviposition does not occupy more than one minute, and the same females were observed to lay again 5 to 7 minutes afterwards.*

On lifting off the covering of the scale the egg, a whitish, transparent elliptic body, is observed on the ventral part of the body of the Black Scale. It is round at one end and has an appendage in the form of a hook at the other; this hook was never seen to be inserted into the body of the scale-insect and may be regarded as an embryonic appendage. The egg adheres always to the body of the host thanks to the stickiness of both; it never remains on the leaf and when the male larva is torn off it can be easily seen.

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* *Aphytis* visits the male scales only for oviposition purposes. It has never been seen feeding on the body juices of the scale (*cf.* the habit of *A. chrysomphali* on *Aspidiotus destructor*, Sign.).

Usually only one egg was seen on a male larvae; rarely 2–3 eggs were observed; in no case, however, more than one parasite larva. The early larval stages of the parasite are always to be found on the ventral or lateral part of the male scale. They are ball-like, displaying under magnification of 40 x or 80 x a clear segmentation of the body (14 segments). The first segment is button-like, the last ones are small and forming the bluntly ended anal part. In the middle of the body the stomach is to be seen, being disproportionately large as compared with the total body cavity.

The larva begins to feed on the host as soon as it leaves the egg, the connection between host and parasite soon becoming so close that it is very difficult to separate them, and much care must be taken in order not to hurt one of them in doing so. When taken off and laid on another healthy male scale it immediately sticks to it and is hardly separable after half an hour.

Pupal Stages.

The prepupa varies in colour from light yellow-brown to very pale yellow. It is characterised by the mallet-like head, first contours of the eyes, and the beginning of the formation of the legs and antennae. The ovipositor of the female is still inside the body.

The life cycle of *A. chrysomphali* is very rapid, not exceeding 12–14 days (from egg to adult). No hyperparasites were observed.

Chilocorus bipustulatus, the Coccinellid predator of Black Scale female adults and larvae, rarely attacks males (and then mostly in March and April when scales are abundant) and leaves unharmed Black Scale males already parasitised by *Aphytis*.

16. Acknowledgments.

On completion of the present paper, it is our pleasant duty to express our warm thanks to our Chief, Mr. E. Ballard, for the keen interest he has taken in the work and for many helpful suggestions.

We should like to stress the fact that the idea of combating Black Scale by winter fumigation, which promises to be of much importance in the control of this serious pest in the Jordan Valley, was for the first time in Palestine suggested and tried on a large scale by Mr. Ballard. And it was he who first suggested that the spread of Black Scale through manure and fruits must be extremely limited, a suggestion that led to extensive testing, which has strongly supported that view.

We are very much obliged to the Manager, Acre Government Stock Farm and Agricultural Station, Mr. B. M. Cameron, for his kind help in every way during the time of our investigation at Acre; to Shafiq Bey Beydoun, who put his commercial grove at Bahja, Acre, at our disposal for large scale tests and fumigation experiments; and last but not least to Mr. D. Ilioff, Manager, Melchett Estate, Migdal, for supplying every facility for our study of Black Scale in the Jordan Valley.

References.

BALACHOVSKY, A. (1932). Etude des Coccides du bassin occidental de la Méditerrannée.—Paris, Lechevalier.

BODENHEIMER, F. S. (1930). Die Schädlingsfauna Palestinas.—Berlin, P. Parey.

BRAWER, A. J. (1929). Geography of Palestine (Haaretz Hebrew).—Tel Aviv.

PRIESNER, H. (1931). The biology of *Chrysomphalus ficus*.—Bull. Minist. Agric. Egypt, no. 117.

QUAYLE, H. J. (1932). Biology and control of citrus insects and mites.—Bull. Calif. Agric. Exp. Sta., no. 542.

TAYLOR, T. H. C. & PAYNE (R. W.). (1935). The campaign against *Aspidiotus destructor*, Sign., in Fiji.—Bull. Ent. Res., **26**, pp. 1–102.

Explanation of Plate XVIII.

Fig. 1.—Two grapefruits : on the left clean, on the right badly attacked by Black Scale—the fruit is undersized and deformed in a characteristic manner.

Fig. 2.—Two lemons : on the left clean, on the right infested with Black Scale.

Fig. 3.—Two oranges : on the left clean, on the right displaying attack by Black Scale.

Fig. 4.—Three orange leaves : *a*, free from scale ; *b* and *c*, infested with Black Scale, the latter being covered with a multitude of young larvae.

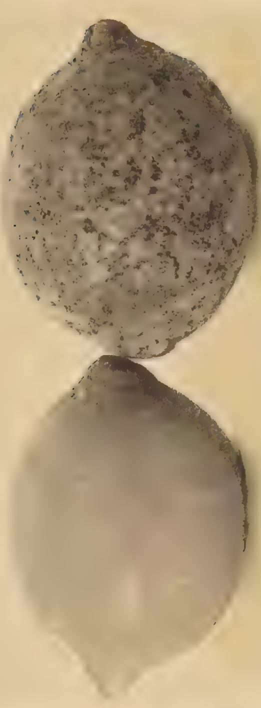

Fig. 2.

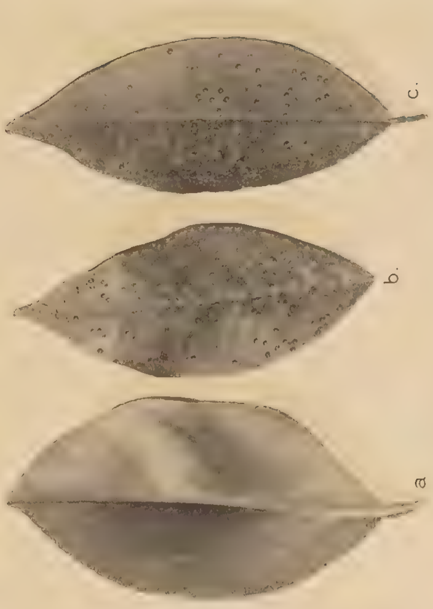

Fig. 4.

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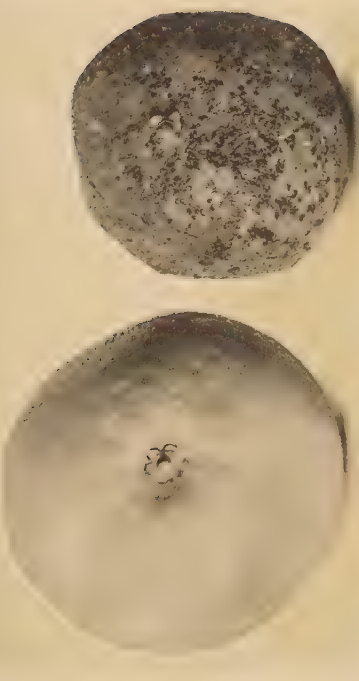

Fig. 1.

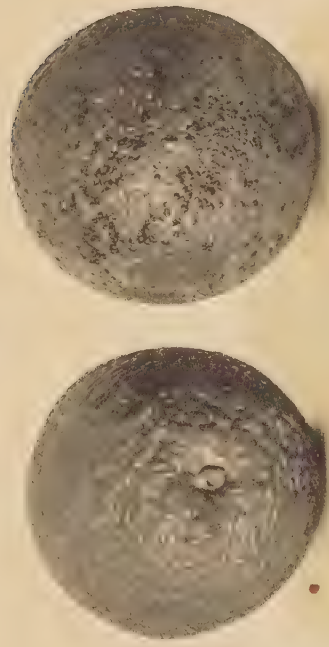

Fig. 3.

COLLECTIONS RECEIVED.

The following collections were received by the Imperial Institute of Entomology between 1st July and 30th September, 1936 :—

Agricultural Officer, Quetta :—12 Diptera, 4 Coleoptera, 2 Lepidoptera, and 4 Gryllidae ; from Baluchistan.

Agricultural Research Service, Khartoum :—12 Coleoptera, 12 Parasitic Hymenoptera, 8 Lepidoptera, 1,300 Isoptera, 2 species of Coccidae, and 38 other Rhynchota ; from the Sudan.

Mr. W. Allan, Entomologist :—12 Lepidoptera ; from Northern Rhodesia.

Mr. E. Ballard, Government Entomologist :—28 Diptera, 2 Parasitic Hymenoptera, 127 Lepidoptera, and 3 Rhynchota ; from Palestine.

Dr. H. Blunck :—11 Parasitic Hymenoptera ; from Germany.

Dr. F. S. Bodenheimer :—7 Coleoptera and 3 Planipennia ; from Palestine.

Mr. T. Borgmeier :—18 Braconidae ; from Brazil.

Mr. H. E. Box :—810 Coleoptera, 100 Parasitic Hymenoptera, 480 Lepidoptera and 3 larvae, 26 Rhynchota, and 9 Orthoptera ; from various localities.

Dr. P. A. Buxton, London School of Tropical Medicine :—5 Bruchidae ; from England.

Mr. F. C. Camargo :—4 Coccinellidae ; from Brazil.

Mr. M. Carleton :—3 Parasitic Hymenoptera ; from England.

Mr. F. G. Chen :—5 Coleoptera and 31 Lepidoptera ; from China.

Chief Entomologist, Pretoria :—74 Coleoptera, 22 Parasitic Hymenoptera, 19 Lepidoptera, and 2 species of Mites ; from South Africa.

Mr. J. K. Chorley, Entomologist :—4 *Glossina* ; from Southern Rhodesia.

Father P. A. Conrads :—113 Coleoptera ; from Tanganyika Territory.

Mr. G. H. Corbett, Government Entomologist :—300 Diptera and 56 pupa cases, 73 Coleoptera, 252 Parasitic Hymenoptera, 55 other Hymenoptera, 31 Lepidoptera, 20 Rhynchota, 2 Orthoptera, and 3 Dermaptera ; from Malaya.

Coryndon Memorial Museum.—791 Coleoptera ; from East Africa.

Mr. J. P. da Fonseca :—5 Coleoptera ; from Brazil.

Mr. R. Delmas :—5 Diptera and 40 Parasitic Hymenoptera ; from France.

Miss Z. Dickson :—13 Rhynchota and 12 Orthoptera ; from Arabia.

Director of Agriculture :—10 Diptera and 3 pupa cases ; from St. Vincent.

Director of Agriculture :—2 species of Coccidae ; from the Seychelles.

Director of Agriculture :—12 Coleoptera ; from Zanzibar.

Mr. A. P. Dodd :—4 Curculionidae ; from Queensland.

Mr. H. L. Dolton :—9 Parasitic Hymenoptera and 3 Lepidopterous larvae ; from England.

Mr. V. H. W. Dowson :—4 Siphonaptera, 4 Culicidae, 42 other Diptera, 147 Coleoptera and 20 early stages, 20 Parasitic Hymenoptera and 11 cocoons, 80 other Hymenoptera, 216 Lepidoptera, and 10 early stages, 7 Thysanoptera, 38 Rhynchota, 9 Orthoptera, 3 Spiders, and 10 tubes of infected dates ; from Iraq.

Mr. L. J. Dumbleton :—8 Parasitic Hymenoptera ; from South Australia.

Dr. H. S. Evans :—134 Formicidae ; from the Fiji Islands.

Mr. R. G. Fennah :—128 Curculionidae ; from the British West Indies.

Dr. L. Fulmek :—14 Braconidae ; from Austria.

Mr. J. C. M. Gardner, Systematic Entomologist :—72 Curculionidae ; from the United Provinces, India.

Mr. S. Garthside :—3 Diptera, 3 Coleoptera, 55 Parasitic Hymenoptera, and 8 Planipennia ; from England.

Government Entomologist, Coimbatore :—63 Diptera and 2 pupa-cases, 56 Coleoptera, 3 Formicidae, 35 Lepidoptera, 2 slides of Coccidae, 26 other Rhynchota, and 100 Mites : from South India.

Government Entomologist, Lyallpur :—26 Coleoptera, 53 Lepidoptera, 26 species of Aphidae, and 2 other Rhynchota ; from the Punjab, India.

Mr. E. Hargreaves, Government Entomologist :—2 *Cordylobia*, 11 *Auchmeromyia* 197 other Diptera and 5 pupa cases, 59 Coleoptera, 80 Parasitic Hymenoptera, 9 other Hymenoptera, 86 Lepidoptera, 550 Isoptera, 6 Rhynchota, 2 Orthoptera, 4 *Hemimerus*, 2 Chrysopidae, and 3 Trichoptera ; from Sierra Leone.

Mr. H. Hargreaves, Government Entomologist :—35 Diptera ; from Uganda.

Mr. W. V. Harris, Entomologist :—5 Diptera, 7 Coleoptera, 41 Parasitic Hymenoptera, and 6 Rhynchota ; from Tanganyika Territory.

Imperial Chemical Industries, Ltd. :—2 species of Coccidae ; from England and Brazil.

Indian Museum, Calcutta :—7 Parasitic Hymenoptera ; from India.

Institute for Plant Diseases, Buitenzorg :—9 Curculionidae and 50 Lepidoptera ; from the Dutch East Indies.

Miss D. J. Jackson :—48 Parasitic Hymenoptera and 50 cocoons ; from Scotland.

Mr. S. G. Jary :—150 Parasitic Hymenoptera ; from England.

Mr. G. J. Kerrich :—80 Parasitic Hymenoptera ; from England.

Mr. C. D. Knight :—529 Coleoptera and 219 Rhynchota ; from Kenya Colony.

Mr. R. A. Lever, Government Entomologist :—25 Siphonaptera, 35 Culicidae, 3 Tabanidae, 86 other Diptera and 50 early stages, 131 Coleoptera, 162 Parasitic Hymenoptera, 37 Formicidae, 31 Lepidoptera, 84 Rhynchota, 40 Psocidae, 39 Orthoptera, 3 Thysanura, and 10 Mallophaga ; from the Solomon Islands.

Mr. C. J. Louwerens :—72 Coleoptera ; from Java.

Mrs. K. C. Mackay :—1 Tipulid and 1 Staphylinid ; from Ireland.

Mr. H. M. Morris, Government Entomologist :—15 Rhynchota ; from Cyprus.

Dr. C. F. W. Muesebeck :—36 Braconidae ; from the United States of America.

Mr. R. W. Mungomery :—28 Diptera ; from North Queensland.

Dr. J. G. Myers :—41 Diptera, 23 Coleoptera and 4 larvae, 150 Parasitic Hymenoptera and 50 cocoons, 2 other Hymenoptera, 3 Thysanoptera, and 5 Orthoptera ; from Tropical America.

Mr. E. F. Peck, Veterinary and Agricultural Officer :—6 Coleoptera and 12 early stages, 32 Formicidae, 2 Lepidopterous cocoons and samples of infected Sorghum ; from British Somaliland.

Messrs. Pullman Car Company :—3 Dermestidae ; from England.

Dr. P. Regnier :—6 Coleoptera and 98 Parasitic Hymenoptera ; from Morocco.

Dr. K. Schedl :—7 Lepidopterous early stages ; from Brazil.

Selangor Museum :—56 Coleoptera ; from Malaya.

Mr. Nihat Shevket :—13 Coleoptera, 30 Parasitic Hymenoptera, 20 Thysanoptera, 22 Rhynchota, and 20 Mites ; from Asiatic Turkey.

Mr. H. W. Simmonds, Government Entomologist :—1 Phasmid ; from Fiji.

Mr. A. W. Stelfox :—172 Parasitic Hymenoptera and 200 cocoons ; from Ireland.

Prof. C. Strickland :—6 Parasitic Hymenoptera ; from Calcutta, India.

Dr. K. Subrahmanian :—36 Coleoptera, 11 Rhynchota, and 11 Orthoptera ; from Burma.

Mr. T. V. Subramaniam :—150 Parasitic Hymenoptera and 1 species of Mite ; from Mysore, India.

Mr. E. L. Taylor :—8 Vespidae ; from England.

Dr. A. L. Tonnoir :—352 Parasitic Hymenoptera and 2 species of Aphidae ; from Australia.

Mr. A. C. Trott :—15 Coleoptera, 3 Rhynchota, and 3 Orthoptera ; from Persia.

Mr. R. Veitch, Chief Entomologist :—61 Coleoptera ; from Queensland.

Mr. H. A. von Weiss-Wichert :—70 Parasitic Hymenoptera ; from Germany.

Mr. A. C. W. Wagner :—19 Parasitic Hymenoptera and 10 cocoons ; from Germany.

West Java Experiment Station :—19 Coleoptera ; from Java.

Mr. F. X. Williams :—128 Diptera, 5 Hispidae, and 2 Lepidoptera ; from Hawaii.

Mr. F. Wilson :—7 Diptera, 10 Coleoptera, 30 Parasitic Hymenoptera, and 3 Lepidoptera ; from France.

Mr. G. N. Wolcott :—9 Coleoptera ; from Porto Rico, etc.

Zoological Museum, Oslo :—6 Parasitic Hymenoptera ; from Norway.

Dr. F. Zumpt :—10 Coleoptera ; from Asia.

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